BIODIVERSITY MANAGEMENT PLAN
SIAM CEMENT GROUP
LAMPANG MINE

BY THE FOREST RESTORATION RESEARCH UNIT

CHIANG MAI UNIVERSITY

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Terrace in Phase-1 pit newly planted with saplings of native forest tree species.
Cover photos – Entrance to conservation forest (background); frog, *Polypedates leucomystax* (Gravenhorst) 1829 (left); spotted leopard cat, *Felis bengalensis,* centre; Asian barred owlet *Glaucidium curuloides* (right)

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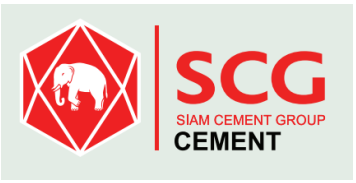

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Tree nursery for forest restoration at the Lampang

OVERVIEW

This Biodiversity Management Plan (BMP), developed by Chiang Mai University's Forest Restoration Research Unit (FORRU-CMU), proposes effective management of key biodiversity features at the Lampang mine of the Siam Cement Group (SCG), northern Thailand. The Plan has been developed from the results of a 5 year field research program at the mine (2014-19) in collaboration with SCG field staff and in accordance with guidelines provided by the company.

It consists of three parts: this Overview, an Executive Summary aimed at decision makers, and a detailed Biodiversity Management Plan, aimed at on-site biodiversity specialists, environmental managers and other stakeholders.

The SCG Mine is operating in a sensitive environmental and social context, because it is located within reserved forest and is adjacent to a national park, where biodiversity conservation is the primary management aim. Lack of economic opportunities in the area, once the mine closes, means that species, currently protected in the conservation zones within the perimeter of the mining concession, are likely to come under threat.

SCG is committed to having a Net Positive Impact on biodiversity. This presents many challenges as the semi-opencast mining practiced at this site completely removes forest habitats and soil and alters water courses. On-site forest restoration can achieve some biodiversity recovery, but not complete recovery to pre-mining levels. Therefore, off-site biodiversity restoration – so-called biodiversity offset - is an essential part of the plan, to achieve a net neutral or positive impact on biodiversity levels.

The BMP consists of the following:

i) an assessment of the geological and biological context of the mine, its workplan and an assessment of the likely impact of SCG's operations on biodiversity;
ii) a description of the original ecosystems on the mine site and an assessment of the biodiversity levels and species occurrences in the conservation zones of the mine concession area and surrounding forest;
iii) a statement of the objectives of biodiversity management;
iv) recommended actions to avoid/minimise habitat loss and restore biodiversity and ecosystems services in general, as well as species-focussed actions directed at preventing extirpation of rare, indicator and keystones species;
v) biodiversity offset activities in the adjacent Tum Pah Thai National Park and
vi) a monitoring and evaluation system to ensure that actions under iv) and v) above achieve the objectives.

Top: Phase-1 pit restoration site. Bottom: Restoration progress after 3 years.

CONTENTS

EXECUTIVE SUMMARY

SCG's semi-open-cast limestone mine in Chae Hom District, Lampang Province is located in a reserved forest area, adjacent to Tum Pah Thai National Park, recognised for its high biodiversity. Mining has a severe impact on biodiversity, notably complete removal of vegetation and top soil from the pits, whilst protected forest within the security provided by SCG (59% of the area) conserves some biodiversity and provides essential biological resources for ecological restoration. In addition, mine operations create dust, noise and are a potential source of water pollution, all which impact biodiversity. However, SCG is closely monitoring indicative environmental variables and, at present, they are all within legislated acceptable limits. Invasion of the site by the exotic shrub, *Leucaena leucocephala* is a serious concern, because it limits tree establishment during forest restoration and outcompetes native plant species.

Seasonally dry bamboo-deciduous forest is the main repository of biodiversity on the mine site. The forest in the conservation and buffer zones is in a state of advanced regeneration following selective logging. Surveys resulted in fairly complete knowledge of the floral diversity of the remnant forest. All plant habits are well represented except for epiphytes. Many of the tree species are locally rare. The remnant forest supports a diverse but otherwise unremarkable bird community. The mammal community is functionally intact and includes several species of conservation concern. The presence of several rare or endangered reptile species presents a major opportunity for conservation. Aquatic habitats, though unremarkable in terms of their own biodiversity, support terrestrial biodiversity, particularly during the dry season.

FORRU-CMU were engaged to gather data related to biodiversity on the mine site and to use the data to compile this Biodiversity Management Plan. The main aim of the plan is to assist SCG to contribute towards national biodiversity objectives and towards meeting Thailand's obligations under the Convention on Biodiversity. Specific goals are: to increase ecosystem biomass, rebuild ecosystem structure, restore biodiversity and re-establish ecosystem functioning through habitat restoration and biodiversity offsetting.

Recommendations were:

1. Maintain and enhance current site-security measures, particularly to prevent encroachment and exclude livestock from the conservation forest and restoration sites.
2. Implement comprehensive fire prevention and suppression measures including: appointment of officers to monitor fires within 10 km of the mine, using NASA's Fire Information and Resource Management System; build a fire tower equipped with a

drone, to track on-coming fires and train and maintain a fire suppression team; maintain fire suppression equipment and support local communities with fire prevention.

3. Protect existing forest to conserve biodiversity and support ecological restoration: reverse and prevent the invasion of forest areas by invasive exotic plant species.
4. Ensure no further forest clearance, except that needed to open the Phase 2 & 3 pits.
5. Annually verify maintenance of forest cover, using satellite imagery.
6. Dredge ponds (silt traps) periodically, to maintain aquatic habitats.
7. Restore forests and maintain and increase connectivity among forest patches, by following established procedures to implement the framework species method, whilst also maximizing use of seeds and seedlings, harvested during forest clearance of subsequent pits.
8. Implement a comprehensive *L. leucocephala* eradication program, focusing first on the restoration plots and moving outwards to eliminate seed sources, using both mechanical removal and herbicides as appropriate. Experiment with adding bamboos to forest restoration planting, as they naturally suppress *L. leucocephala*.
9. Monitor the species of conservation concern listed in the report annually using appropriate protocols for each animal class and rare tree species.
10. Include saplings of rare tree species amongst those planted for forest restoration.
11. Re-introduce extirpated orchid species.
12. Maintain measures to prevent hunting.
13. For declining populations of species of concern, implement supplementary feeding, habitat manipulation or captive breeding as appropriate.
14. Instigate a study to determine the effects of dust and mitigation measures on the primary production and biomass accumulation of vegetation, comparing roadside with forest-interior vegetation.
15. Instigate a study on the effects of noise on bird behaviour, particularly nesting success.
16. Review and, if necessary, modify dust- and noise-mitigation measures on the mine, if these studies show a deleterious effect on plants and wildlife, particularly on the species of concern.
17. Perform biodiversity offset, by restoring bamboo-deciduous forest in Tum Pah Thai National Park covering 11.6 – 12.3 km^2 depending on the scenarios listed in Table 7.2. Ensure comprehensive stakeholder involvement and make maximum use of data from FORRU-CMU's pilot restoration plots already established in the park.
18. Implement a cpmprehensive monitoring program to evaluate the success of all above recommendations to conserve and enhance biodiversity, including annual vegetation surveys in both conservation and restored forest areas; bird surveys using the McKinnon's curve method and camera trapping for other animals.
19. Pursue opportunities for education and outreach through the existing education centre.

บทสรุปผู้บริหาร

เหมืองหินปูนบริษัทปูนซิเมนต์ไทย (ลำปาง) อำเภอแจ้ห่ม จังหวัดลำปาง เป็นเหมืองแบบ semi-open-cast ตั้งอยู่ในพื้นที่ป่าสงวนที่ติดกับอุทยานแห่งชาติถ้ำผาไทเป็นพื้นที่ที่มีความหลากหลายทางชีวภาพสูง การทำเหมืองส่งผลกระทบอย่างรุนแรงต่อความหลากหลายทางชีวภาพโดยในพื้นที่เหมืองพืชพรรณและหน้าดินถูกทำลายไปจนหมด ในขณะที่พื้นที่ป่าในเขตประทานบัตรประมาณ 59% ซึ่งถูกกันไว้เป็นแนวกันชน (buffer zone) ได้รับการดูแลและป้องกันเป็นอย่างดี พื้นที่ในส่วนนี้จึงเป็นแหล่งทรัพยากรทางชีวภาพที่สำคัญสำหรับการฟื้นฟูระบบนิเวศ นอกจากนั้นการทำเหมืองยังทำให้เกิดมลภาวะในรูปของฝุ่น เสียง และอาจทำให้เกิดการปนเปื้อนของแหล่งน้ำซึ่งจะส่งผลต่อความหลากหลายทางชีวภาพ อย่างไรก็ตามในส่วนนี้ SCG ได้ติดตามตรวจสอบดัชนีชี้วัดทางสิ่งแวดล้อมต่างๆ อย่างใกล้ชิดและในปัจจุบันคุณภาพของสิ่งแวดล้อมในพื้นที่ยังอยู่ในเกณฑ์ที่กำหนด ปัญหาสำคัญที่พบในปัจจุบันคือการรุกเข้ามาในพื้นที่ของต้นกระถินยักษ์ (*Leucaena leucocephala*) ซึ่งเข้าไปขัดขวางการฟื้นฟูพื้นที่และการเติบโตของไม้ท้องถิ่น

ป่าส่วนใหญ่ในพื้นที่เป็นป่าผลัดใบผสมไผ่ ป่าในพื้นที่แนวกันชนและพื้นที่ป่าอนุรักษ์เป็นสังคมพืชที่ฟื้นตัวหลังจากการทำไม้ซึ่งค่อนข้างสมบูรณ์ จากการสำรวจทำให้ทราบถึงชนิดพรรณไม้ทั้งหมดที่พบได้ในพื้นที่และทำให้เห็นว่าในพื้นที่มีพรรณไม้เกือบทุกกลุ่มที่สามารถพบได้ในป่าผลัดใบของประเทศไทยยกเว้นกลุ่มของไม้อิงอาศัย ต้นไม้หลายชนิดเป็นชนิดที่พบได้น้อยในพื้นที่ (locally rare) ในพื้นที่ป่าที่ได้รับการอนุรักษ์พบว่ามีความหลากหลายของนกสูงแต่ว่าไม่มีชนิดใดที่น่าสนใจเป็นพิเศษ พบสัตว์เลี้ยงลูกด้วยนมหลายชนิดรวมถึงชนิดที่ควรให้ความสนใจในการอนุรักษ์ สัตว์อีกกลุ่มที่น่าสนใจในการดำเนินการเพื่อการอนุรักษ์ได้แก่สัตว์เลื้อยคลาน ระบบนิเวศแหล่งน้ำในพื้นที่อาจจะมีความหลากหลายทางชีวภาพไม่มากแต่ยังทำหน้าที่สำคัญในการเป็นแหล่งทรัพยากรในการดำรงชีวิตของสัตว์ต่างๆที่อาศัยอยู่บนบก โดยเฉพาะอย่างยิ่งในช่วงหน้าแล้ง

FORRU-CMU ได้รับมอบหมายให้รวบรวมข้อมูลเกี่ยวกับความหลากหลายทางชีวภาพภายในพื้นที่ของบริษัทปูนซิเมนต์ไทย(ลำปาง) เพื่อจัดทำรายงาน Biodiversity Management Plan โดยเป้าหมายหลักของรายงานฉบับนี้คือสนับสนุน SCG ในการมีส่วนร่วมเพื่อบรรลุวัตถุประสงค์ด้านความหลากหลายทางชีวภาพของประเทศ รวมถึงเป็นส่วนหนึ่งของการบรรลุพันธกรณีของประเทศไทยภายใต้อนุสัญญาว่าด้วยความหลากหลายทางชีวภาพ ส่วนเป้าหมายที่เฉพาะเจาะคือการเพิ่มมวลชีวภาพในระบบนิเวศ ฟื้นฟูโครงสร้างของระบบนิเวศ ฟื้นฟูความหลายหลายทางชีวภาพรวมถึงการทำงานของระบบนิเวศผ่านการฟื้นฟูระบบนิเวศและการชดเชยผลกรทบด้านความหลากหลายทางชีวภาพ

ข้อเสนอแนะ:

1. รักษาระดับหรือเพิ่มความเข้มข้นในการป้องกันพื้นที่ โดยเฉพาะอย่างยิ่งการป้องกันพื้นที่จากการบุกรุกและพยายามกันปศุสัตว์ไม่ให้เข้ามาในพื้นที่ป่าอนุรักษ์ และป่าฟื้นฟู
2. ดำเนินมาตรการป้องกันและควบคุมไฟป่าอย่างครอบคลุม ได้แก่ มอบหมายให้เจ้าหน้าที่ตรวจสอบการเกิดไฟป่าภายในระยะ 10 กม. จากเหมือง โดยใช้ระบบ Fire Information and Resource Management System ของ

NASA สร้างหอดูไฟและใช้โดรนในการติดตามสถานการณ์ไฟป่าในบริเวณใกล้พื้นที่เหมือง สร้างทีมดับไฟป่าพร้อมเครื่องมือที่มีความพร้อม รวมถึงให้การสนับสนุนชุมชนในพื้นที่ในการป้องกันไฟป่า

3. ป้องกันและรักษาพื้นที่ป่าที่มีเพื่ออนุรักษ์ความหลากหลายทางชีวภาพและสนับสนุนการฟื้นฟูระบบนิเวศ ป้องกันไม่ให้พันธุ์ไม้ต่างถิ่นเข้ามาในพื้นที่ป่า
4. ตรวจสอบให้แน่ใจว่าไม่มีการทำลายพื้นที่ป่าเพิ่มขึ้นนอกจากส่วนที่จำเป็นสำหรับการทำเหมืองในระยะที่ 2 และ 3
5. ติดตามตรวจสอบพื้นที่ป่าทุกปีโดยใช้ภาพถ่ายจากดาวเทียม หรือ โดรน
6. ขุดลอกสระ (อ่างดักตะกอน) เป็นระยะ เพื่อรักษาระบบนิเวศแหล่งน้ำ
7. ฟื้นฟูและรักษาพื้นที่ป่าที่มีและสร้างความต่อเนื่องของพื้นที่แต่ละผืนโดยใช้วิธีการพรรณไม้โครงสร้างที่ปรับให้เหมาะกับพื้นที่เหมือง และพยายามใช้ประโยชน์จากเมล็ดและกล้าไม้ที่นำออกมาเมื่อมีการเปิดพื้นที่ใหม่เพื่อการทำเหมือง
8. วางแผนในการกำจัดกระถินยักษ์ออกจากพื้นที่ โดยเริ่มจากพื้นที่แปลงฟื้นฟูป่า จากนั้นจึงกำจัดแม่ไม้ในพื้นที่โดยใช้แรงงานคนหรือสารกำจัดวัชพืชแล้วแต่ความเหมาะสม ทดลองการควบคุมกระถินยักษ์ในพื้นที่ฟื้นฟูโดยการปลูกไผ่ผสมไปในพื้นที่เพื่อให้ไผ่ไปควบคุมการเติบโตของกระถินยักษ์
9. ติดตามสิ่งมีชีวิตตามรายการที่ระบุว่าควรให้ความสำคัญในการอนุรักษ์ทุกปีโดยใช้วิธีการที่เหมาะสมสำหรับสัตว์และพืชแต่ละกลุ่ม
10. ปลูกกล้าไม้ของพืชหายากรวมกันพรรณไม้อื่นที่ใช้ในการฟื้นฟูพื้นที่
11. ทำโครงการเพื่อนำกล้วยไม้ที่สูญพันธุ์ไปจากพื้นที่กลับคืนมา
12. รักษามาตรการที่ใช้ในการป้องกันการล่าสัตว์ในพื้นที่ไว้
13. ถ้าสัตว์ที่ต้องการอนุรักษ์มีจำนวนประชากรลดลง อาจจัดหาแหล่งอาหารเสริมให้ ปรับพื้นที่อาศัย หรือ นำมาขยายพันธุ์ตามความจำเป็น
14. ศึกษาผลกระทบจากฝุ่นต่อการเติบโตและการสะสมมวลชีวภาพของพืชเพื่อหาทางลดผลกระทบโดยอาจทำการศึกษาเปรียบเทียบระหว่างพืชที่อยู่ในพื้นที่ที่อยู่ติดถนนกับในป่า
15. ศึกษาผลกระทบของเสียงต่อพฤติกรรมของนก โดยเฉพาะอย่างยิ่งผลต่อความสำเร็จในการสร้างรังและวางไข่
16. ทบทวนและ(ถ้าจำเป็น)ปรับเปลี่ยนวิธีการลดผลกระทบจากฝุ่นและเสียงถ้าหากพบว่ามีผลกระทบต่อพืชและสัตว์ในพื้นที่โดยเฉพาะอย่างยิ่งชนิดที่ต้องการอนุรักษ์
17. ชดเชยผลกระทบต่อความหลากหลายทางชีวภาพโดยฟื้นฟูป่าผลัดใบผสมไผ่ในพื้นที่อุทยานแห่งชาติถ้ำผาไท 11.6-12.3 ตารางกิโลเมตร ขึ้นอยู่กับการฟื้นฟูพื้นที่เหมือง ตามscenario ที่แสดงไว้ในตาราง 7.2 โดยการดำเนินงานควรส่วนร่วมจากทุกภาคส่วน ทั้งนี้สามารถใช้ข้อมูลจากแปลงฟื้นฟูที่ทาง FORRU-CMU เคยดำเนินการในอุทยานแห่งชาติถ้ำผาไทมาประกอบการทำงานได้
18. ติดตามตรวจสอบและประเมินผลการดำเนินงานในกิจกรรมทุกอย่างที่ได้แนะนำไว้เพื่อการอนุรักษ์และเพิ่มความหลากหลายทางชีวภาพอย่างครอบคลุม รวมถึงการสำรวจพรรณไม้ในพื้นที่อนุรักษ์และพื้นที่ฟื้นฟูทุกปี สำรวจนกโดยใช้วิธี McKinnon's curve และสำรวจสัตว์อื่นๆโดยใช้กล้อง camera trap
19. ให้การศึกษาและเผยแพร่ข้อมูลเกี่ยวกับการฟื้นฟูพื้นที่และการอนุกรักษ์โดยใช้ศูนย์การเรียนรู้ที่มี

1 THE MINE

1.1 LOCATION AND HISTORY

The Siam Cement Public Company Limited (SCG) operates a mine in Chae Hom district, Lampang Province, Northern Thailand (17˚57'16"N, 99˚26'05" E; elevation 400 m).

This report plans for biodiversity conservation at SCG's Lampang mine.

The mine has been open for operation since 1993, the latest mining concession agreement (*prathanabat*), which came into force in the year 2017, will expire in 2042 AD. It comprises 22 plots, covering 10.2848 km^2, and provides for two types of mineral extraction: shale and limestone and for the cement industry (Table 1.1). The total amount of limestone extracted has exceeded 23.69 megatons, since the mine opened.

Table 1.1 – Mineral extraction under the 2017-42 concession agreement

Extraction Type	Number of Concession	Area km^2
Limestone	17	7.9792
Shale	5	2.3056
Total	22	10.2848

Mining operations will impact only about 40% of the total concession area. Most of the rest is being preserved as a 'buffer zone', to shield the surrounding landscape and neighbouring communities from the environmental impacts of excavation which includes conservation forest areas.

The mine is located within the Mae Sai Kham Reserved Forest (Fig. 1.12), which was established in 1965. Before mining commenced, most of the concession area was covered in degraded, but recovering, teak forest (logged and subsequently invaded by bamboos). The area had been logged for teak and other valuable timbers since 1864 by the British Borneo Company, Ltd. Logging ceased countrywide in 1989, due to a national logging ban, promulgated by the Chatichai government.

In Reserved Forest – former logging concession

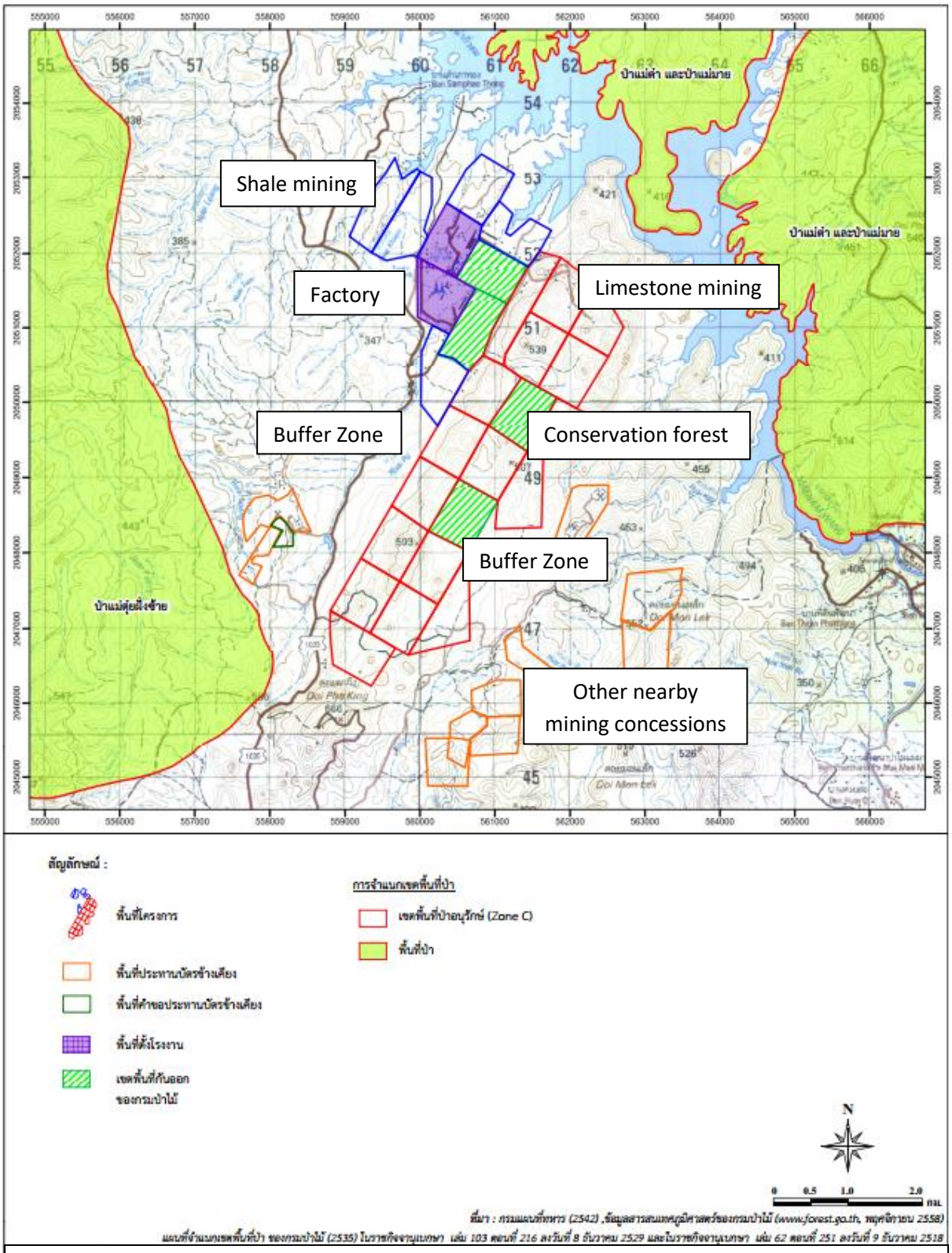


Figure 1.1 – Map of SCG Lampang mine concession area, showing limestone and shale mining plots and conservation forest in the mining area. The area around the mine plots is being conserved as a buffer zone.

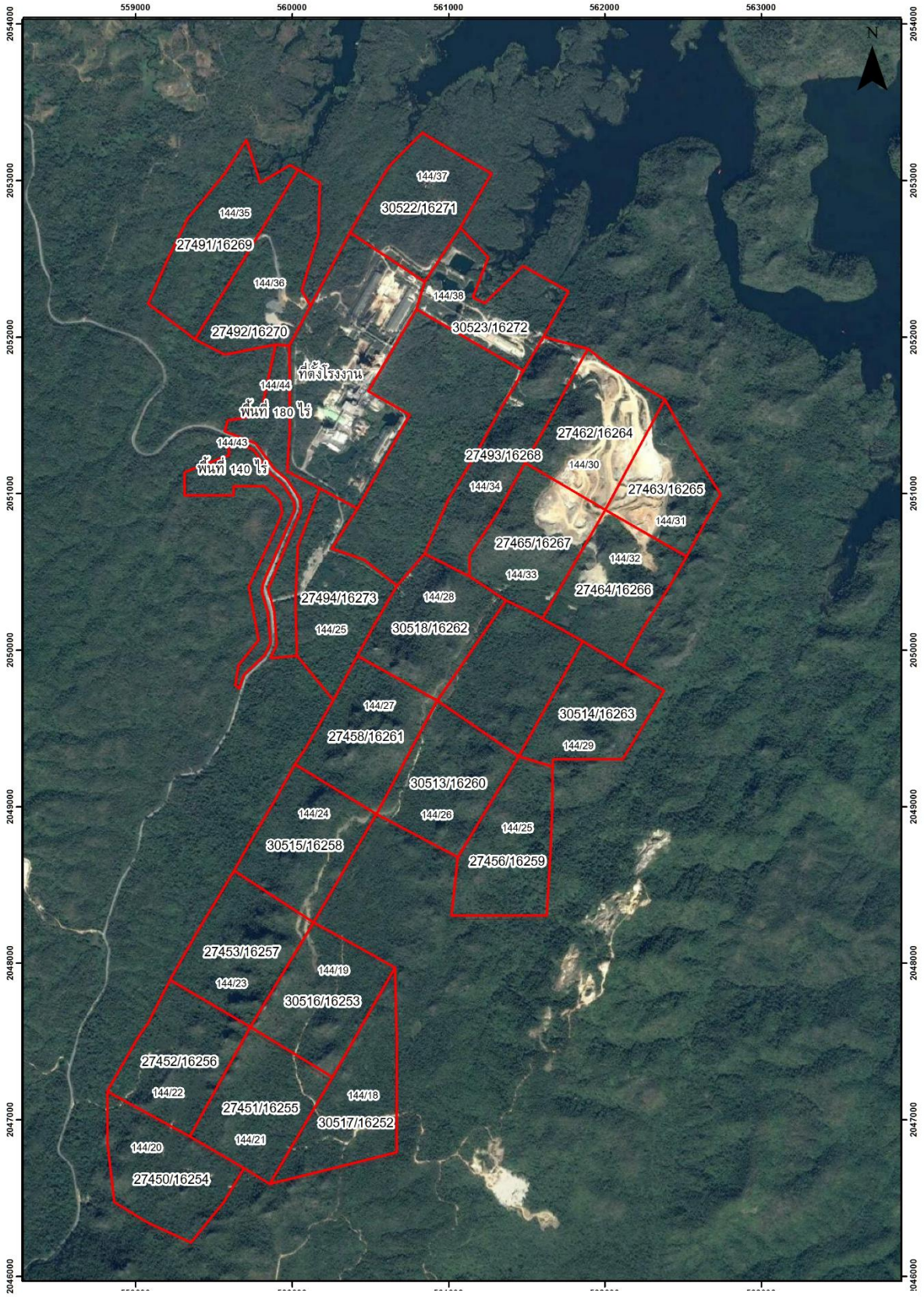


Figure 1.2 – Google Earth image of the SCG Lampang mine concession area (2018), overlaid with mine compartments and their numbers. The Phase-1 Pit is shown top right and the cement factory top left. Note dense forest in buffer zone around the mining compartment boundaries.

1.2 GEOLOGY & CLIMATE

The mine is in the Mae Wang Basin

The mine is located amongst limestone mountains in the southern part of the Wang River basin, which is part of the Greater Ping Basin and the Chao Phraya Watershed.

1.2.1 GEOLOGY

Jagged, marine, Triassic, limestone mountains thrown up with the Himalayas

The limestone at the mine is part of the Mae Than Deposit, which formed during the Triassic period (252-201 million years ago) due to the accumulation of the exoskeletons of marine organisms, when northern Thailand was submerged beneath a shallow sea. The limestone layer, which in some places can be up to 3 km thick, was uplifted and tilted to form mountains, from around 50 million years ago onwards, as India collided with the rest of Asia, throwing up the Himalayas. Consequently, the area of the Lampang mine comprises scattered limestone hills, with jagged and rounded peaks, up to an altitude of 550 m above mean sea level. Flatter areas between the mountain peaks average around 380 m above sea level

1.2.2 CLIMATE

Seasonally dry monsoonal climate

The climate of Lampang is classified as Aw by the Köppen-Geiger system. Annual precipitation averages 1,082 mm, whilst mean annual temperature 26.3 °C (Fig 1.3).

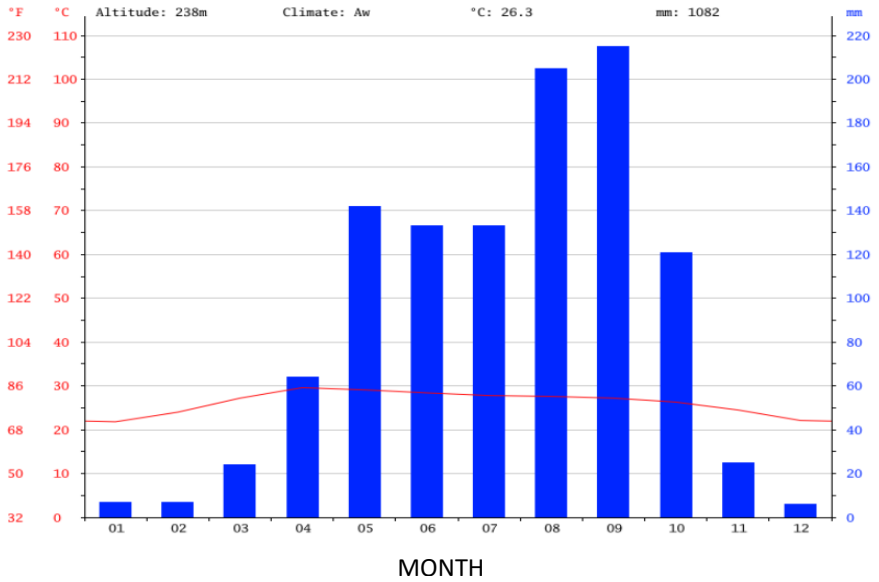


Figure 1.3 - Mean monthly rainfall and temperature at Lampang City 238 m above sea level.

https://en.climate-data.org/asia/thailand/lampang-province/lampang-2012/#climate-graph

The climate has three distinct seasons:

i) the cool dry season from mid-October to February
ii) the hot dry season from March to April
iii) the rainy season, from May to mid-October

From mid-October to the end of February, the weather is relatively cool (30°C during the day and 10-15°C at night) and dry with little or no rainfall. The temperature in January is the lowest at 13.9 °C. The hot dry season usually starts in March and lasts until early May, but in recent years, it often extends into June. It is characterized not only by scorching temperatures (>40°C during the day and >30°C at night), but also by smoke pollution from forest fires in the surrounding area. This is the most challenging season for the survival of both plants and animals around the mine. Rainfall becomes reliable in June, peaking in August to September and declining rapidly thereafter.

Severe dry season

Figure 1.4 – SCG Lampang limestone quarry, Phase-1 Pit

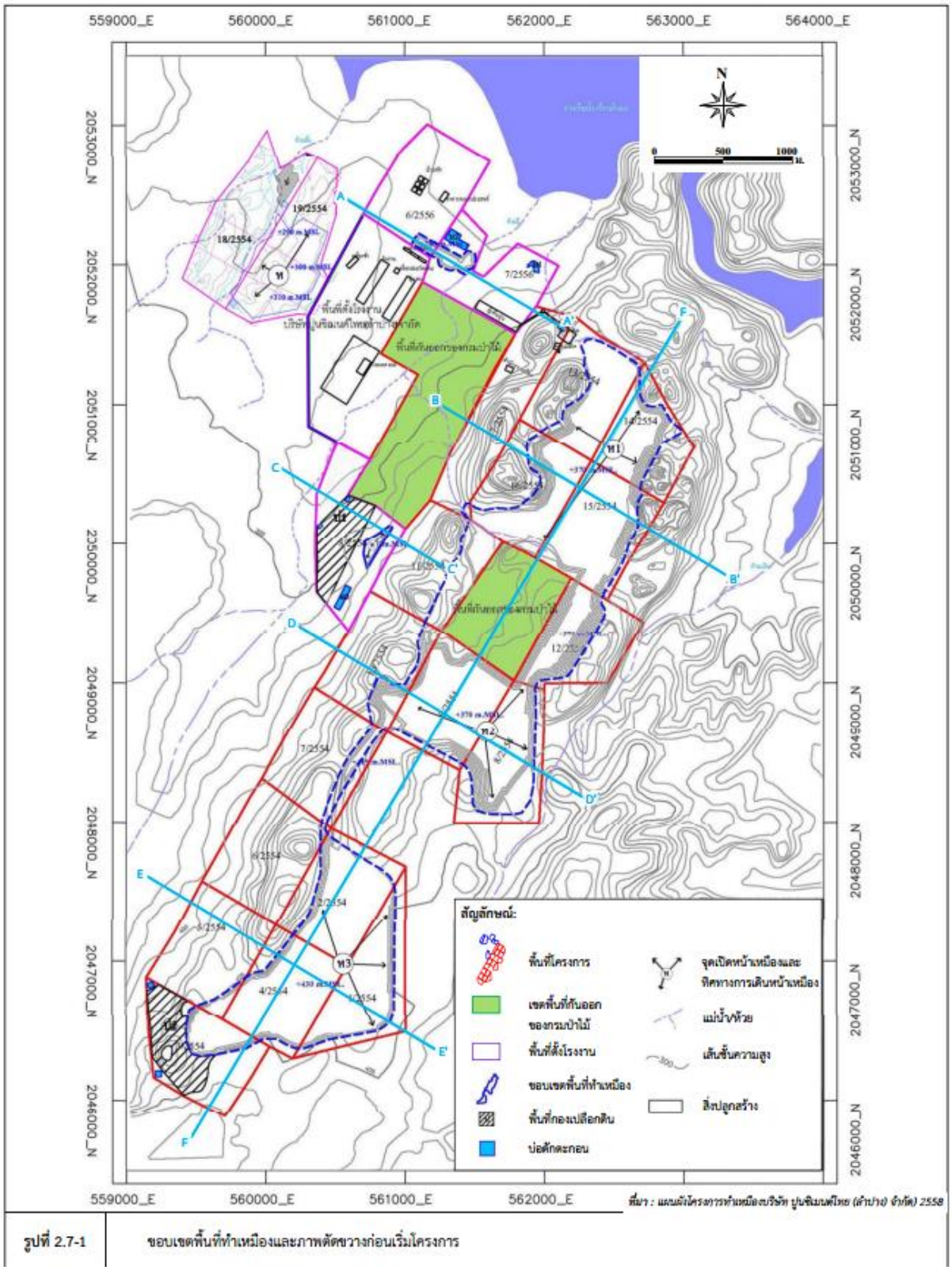
1.3 MINE SITE COMPONENTS

1.3.1 THE PITS

Blasting removes top soil and all biodiversity except some microbes.

Of the total limestone mining concession area (7.9792 sq km), only about 3.8448 sq km will be excavated as quarries in 3 phases. The rest of the area is being preserved as buffer zone forest to shield the surrounding environment from the impacts of the mines (e.g., dust, noise etc.). At the time of writing, excavation of the Phase-1 pit is more or less complete, with excavation of the Phase-2 pit about to begin (Fig 1.5). Two forms of excavation are performed with explosives: undercut blasting to initially open the pit and vertical hole blasting for main limestone extraction. Undercut blasting is performed 4 times per month, extracting approximately 20,000 tons/month. Vertical hole blasting occurs 16 days per month, extracting more than 610,000 tons/month. After blasting, the mined areas are terraced (benching) to contour and stabilize the slopes around the pit walls. This form of mining leaves no remnant biodiversity; only micro-organisms survive in the substrate (Sansupa et al., 2021), albeit heavily depleted. Intensive remedial measures; replacement of top soil and revegetation, are needed to bring about biodiversity recovery on such areas.

Figure 1.5 – SCG Lampang limestone quarry, Phase-1. Pit panorama showing proximity of natural forest



รูปที่ 2.7-1 ขอบเขตพื้นที่ทำเหมืองและภาพตัดขวางก่อนเริ่มโครงการ

Figure 1.6 – The extent of the limestone pits is shown by blue dashed lines. The opening points and direction of cutting for each of the 3 phases are indicated by the white circles and arrows respectively.

1.3.2 TAILINGS AND TOP SOIL STORED ONSITE

The original top soil, removed when clearing forest to prepare the site for the Phase-1 pit, was said to have been stored temporarily "in the pit" but we were unable to track down exactly, where it has been stored and what has become of it.

Information made available, concerning top soil and tailings storage was confusing and contradictory.

Likewise, information received, concerning mine tailings was contradictory and confusing. Mine staff told us verbally in a January 2020 meeting that "no tailings are stored on the mine site; all material is sent to the factory for limestone extraction". However, tailings storage is clearly indicated on the map in Fig. 1.6. Furthermore, the following data appear in an EIA of the mine, approved by the Office of Natural Resources and Environment Policy and Planning (Table 1.2), which stated that "rock and substrates that remain after extraction are stored in 3 locations, with a total storage capacity of 1,971,859 Cubic meters" (SCI Eco Services, 2019).

Table 1.2 – The mine tailings

Phase	Area (rai)	Volume (m^3)	Location (Prathanabat)
1	17	49,859	18/2011
2	150	916,000	8/2013
3	150	916,000	3/2011

Please note that the total volume in the table does not match the total stated in the report. The report also mentions setting up sediment traps to prevent siltation of streams flowing across the mine site.

1.3.3 PRESERVED FOREST AREAS

Forest left on 59% of the site retains plants and animals to foster biodiversity recovery.

According to the EIA only 41% of the concession area will be mined. The rest (59%) is being conserved to form a buffer zone (Fig. 1.7). Such forested areas are located mostly around the edge of the concession area. Not only do they reduce the impact of noise and dust on the surrounding area, but they also provide a refuge for plants and animals, protecting them from the disturbances caused by mining activities. These areas are also a valuable resource for mine rehabilitation work. They provide the seed source, from which planting stock can be grown, opportunities to study tree phenology (to determine optimum seed collection times) and they serve as the target

forest ecosystem for restoration, providing the benchmarks for biomass accumulation, structural development, biodiversity recovery and ecological functioning that define progress with restoration, post-mining. Long term management of the buffer area, in combination with the restoration sites, could provide ecosystem products and services to local communities and contribute towards climate change mitigation (Keppel, et al., 2012).

Remaining forest provides a reference system to define restoration goals

In addition to buffer zone forest, there are 2 isolated remnant blocks of "conservation forest", among the mine concession blocks (indicated in green on Figs 1.6) totally 1.44 sq km, where the Royal Forest Department has banned mining. These also add to the conservation value of the site and are valuable as nuclei for future biodiversity recovery across the area.

Figure 1.7 – Buffer zone teak/bamboo forest near the SCG Limestone Quarry – a tremendous resource to foster post-mining biodiversity recovery.

1.3.4 FOREST RESTORATION SITES

Forest restoration is being implemented on the limestone pits. Although the aim is to cover the entire pit areas (3.8448 sq km), this is inconsistent with Environmental Impact Assessment report, which states that only 2.9696 sq km is earmarked for forest restoration. A modification of the framework species method is being applied, by planting trees that are characteristic of the surround deciduous forest ecosystem types. Restoration of the Phase 1 limestone pit is already well underway and some of the initial results are promising (Fig 1.8).

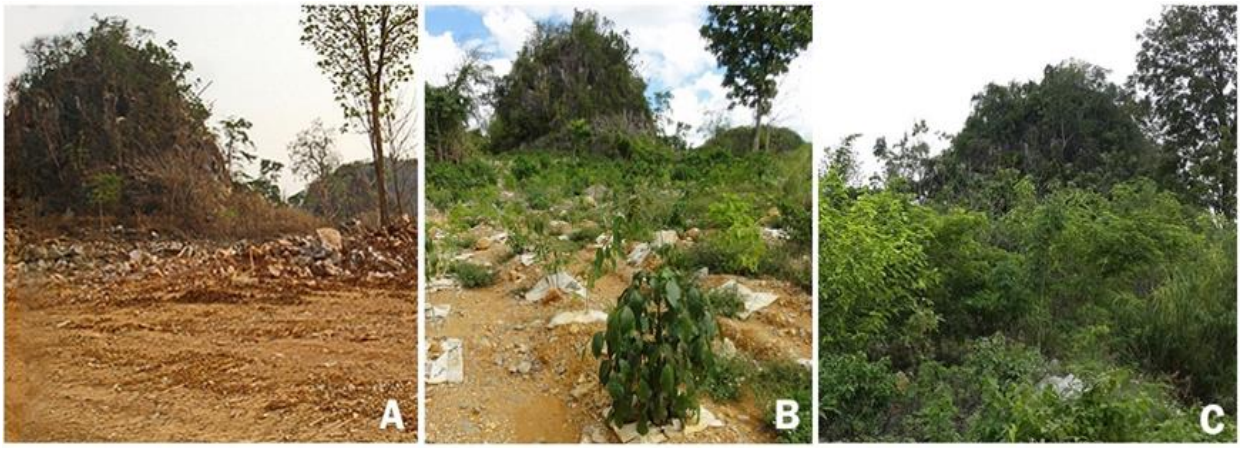


Figure 1.8 - The framework species method of forest restoration is effective on some parts of the pits, especially those areas closest to natural forest. A) August 2012: Siam Cement's limestone mine in Lampang Province, northern Thailand. B) April 2013: after spreading the site with topsoil (60 cm deep), 14 framework tree species were planted, including several Ficus species and native legumes, to improve soil conditions. Corrugated cardboard mulch mats were also applied. C) February 2015: by the end of the third rainy season, canopy closure was achieved and macaque monkeys started visiting the plot to eat figs, in the process naturally dispersing seeds of other species through defecation. Mean survival across species was 64% and relative annual growth rate averaged 91%. (Credit: Siam Cement Group and SE).

1.3.5 BUILDINGS – OFFICE, DEPOTS AND FACTORIES

In addition to the pits, the mine comprises various buildings, including offices, depots, factories and storage facilities (Fig. 1.9). These are concentrated in a clearly defined zone, indicated in purple in the map (Fig. 1.1) with their current position and extent clearly visible in Fig 1.2. The fate of these structures is uncertain, particularly whether they will be retained or repurposed post mine-closure. This is causing uncertainty for biodiversity management planning, since it is unknown whether they will continue to impact on biodiversity or their removal presents an opportunity for biodiversity restoration. Therefore, likely biodiversity reduction is calculated on the basis of 3 scenarios:100% retention/removal of the structures and partial retention.

Figure 1.9 – drone imagery of main built structures at the SCG Lampang mine: top to bottom: factory building, silo, and office and storage building.

1.3.6 ROADS

Similar uncertainties surround the fate of the roads on the mine. We have been unable to obtain data on the length, area and position of the roads and how the road network will change as work progresses with phases 2 and 3. Therefore, before a biodiversity management plan cannot be fully completed. A full plan for road construction/removal must be provided both during the remainder of Phases 2 & 3 and during the mine closure period.

This is important for biodiversity, since roads are the main source of dust around the mine. They dissect and fragment the remaining forest habitat, hindering the movements of wildlife and exacerbating inbreeding depression, and they allow access to forest habitats and therefore facilitate disturbance of it (e.g., hunting, encroachment etc.). A meaningful biodiversity management plan and therefore only be completed once the road plan has been fully prepared and made available.

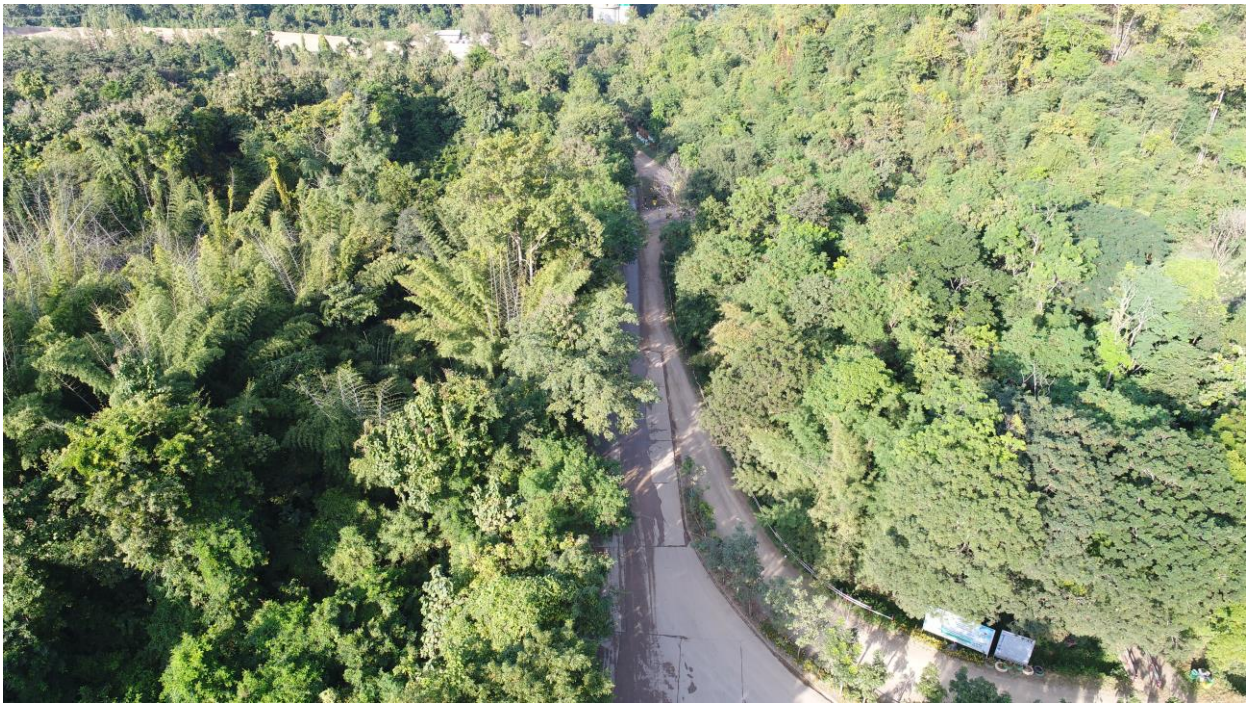


Figure 1.10 – drone imagery of a typical road on the SCG Lampang mine site, near the office building. The roads are wide to take industrial traffic and surface with concrete or compacted soil.

1.3.7 WATER BODIES

No streams run through the pit areas. All water bodies combined constitute just 0.32 % of the concession area.

The Kiew Lom Reservoir, on the northeastern boundary of the mine concession area was constructed by the Royal Irrigation department in 1964, to provide water for agriculture and to mitigate flooding. The reservoir stores water from the Wang River and has two outlets/streams into the mine area: the **Huay Kerm** and the **Huay Poo.** Regulations stipulate that mine operations are not permitted within 50 meters of these streams.

The Kiew Lom Reservoir on the NE mine boundary is a managed local subsistence fishery

Figure 1.11 – Kiew Lom Dam, Lampang Province

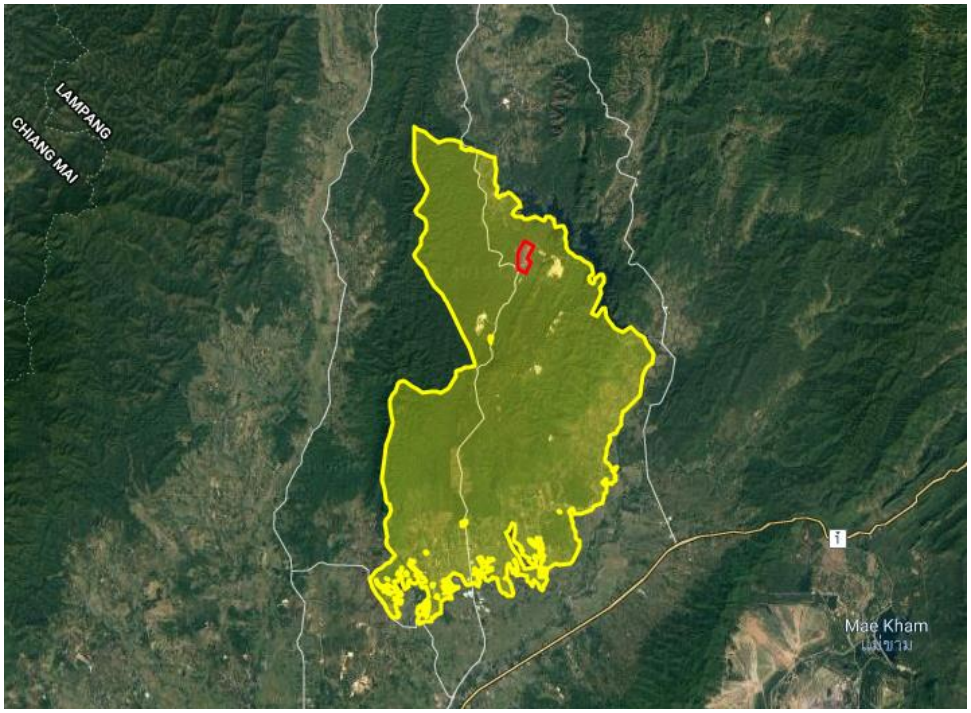


Figure 1.12 – Location of the SCG Lampang mine (red line) within the Mae Sai Kham Reserved Forest Area (yellow boundary) showing the Kiew Lom reservoir to

1.4 The Mining Approach

Semiopen-cut mining reduces disturbance

SCG is using the 'semiopen-cut mining' at the Lampang concession. This involves digging out a "crater" in the top of the mountain. The crater walls remain intact, visually screening the mine from ground view, until the viewer reaches the crater rim. It also minimizes the environmental impact of the mine on the surrounding forest and nearby village communities, reduces noise and dust pollution and includes measures to maximize water efficiency (Fig. 1.13).

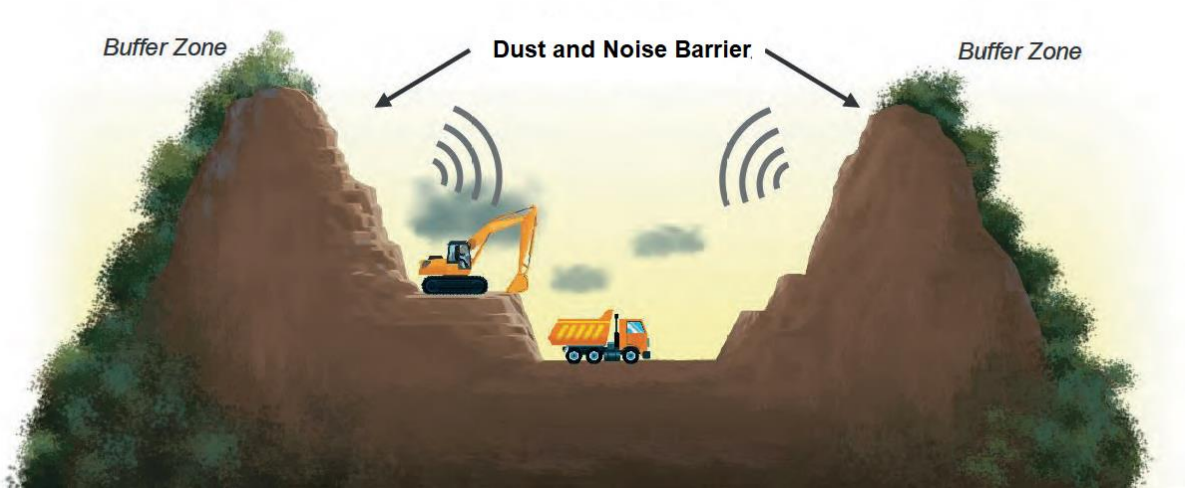


Figure 1.13 – Semiopen-cut mining – contains pollution and visually screens the mine

1.5 The Legal Context

Ecological restoration is a legal requirement

Mine restoration is legally required under Thai law. SCG is legally obligated to implement environmental "corrective measures", specified in the 1992 Environmental Impact Assessment Report (EIA) for the mine site of SCG in Lampang (ONEP, 1992) and under the Forestry Act B.E. 2507, Chapter 2 Section 16 (2) "*Such utilization related to mineral mine under the law on mineral resources and a period of such utilization is no longer than ten years* […] *Asking for, and granting of, permission under paragraph one shall be made in accordance with rule, procedure and condition specified by the Director-General which is approved by the Minister*."

Since the start of the concession in 1992, reforestation has been implemented under the corrective measures described in the EIA with annually progress reports submitted to The Office of Natural Resources and Environment Policy and Planning (ONEP), Royal Forestry Department (RFD) and The National Environment Committee (ONEP, 1992).

Currently, under the New Minerals Act BE 2560 (2017) a mining concession holder must submit plans for restoration, development, utilization and monitoring impacts from mining on the environment and health of people in and around the mine (Section 54) and implement those plans subsequently under Section 68 (8), both during mining and after mine closure. The Act further requires that the concessionaire includes a rehabilitation plan in the EIA mitigation report when the mine opens. According to The Coordinating Committee for Geoscience Programmes in East and Southeast Asia (CCOP), the plan and results of implementation must be reported to the Department of Primary Industry and Mines (DPIM) every 3-5 years, depending on the mitigation measures, approved by the Mineral Committee. The report should include:

i) history of the concession license;
ii) present mining area (photos & layout mining);
iii) pattern of land-use in the end (photos & layout mining);
iv) results of rehabilitation (tree planting) (photos & layout mining);
v) plan for rehabilitation for next 3-5 years (photos & layout mining) and
vi) an account of funds allocated to rehabilitation

1.6 PREVIOUS AND ONGOING REHABILITATION

The first effort of rehabilitation of the mine started in 1992. According to the EIA report, tree planting was implemented on degraded forestland and areas adjacent to the concession plots within the first 10 years after commencing the first mining operations. Fast-growing trees and native trees were planted under the supervision of the Royal Forest Department. As mining ceases on each section of the concession, fast-growing trees are planted to re-establish forest close to its original condition over the pits.

Successful restoration required collaboration with outside experts.

Apart from this obligatory procedure, SCG developed their own rehabilitation plan called "the SCG quarry rehabilitation approach", aimed at returning ecological conditions to pre-mining conditions as closely as possible. However, rehabilitation works from 2000 to 2011 were highly experimental and planted trees did not survive or grow very well. Therefore in 2012, SCG began collaborating with forestry experts from academic institutions to develop systemic processes and techniques for quarry rehabilitation. The mine adopted the framework species technique pioneered in northern Thailand by Chiang Mai University's Forest Restoration Research Unit (FORRU-CMU). Trees of species that could survive well in the harsh conditions after mining and those likely to attract seed-dispersing animals from nearby intact forests were selected and grown from locally collected seed. *Ficus* spp and legumes, which improve the physical structure of the substrate and the nutrient supply respectively were prioritized. Intensive post-planting monitoring enabled rapid improvements to the technique (SCG, 2018a). Restoration areas completed or ongoing are illustrated in Fig. 14. The periods indicated started in 1992.

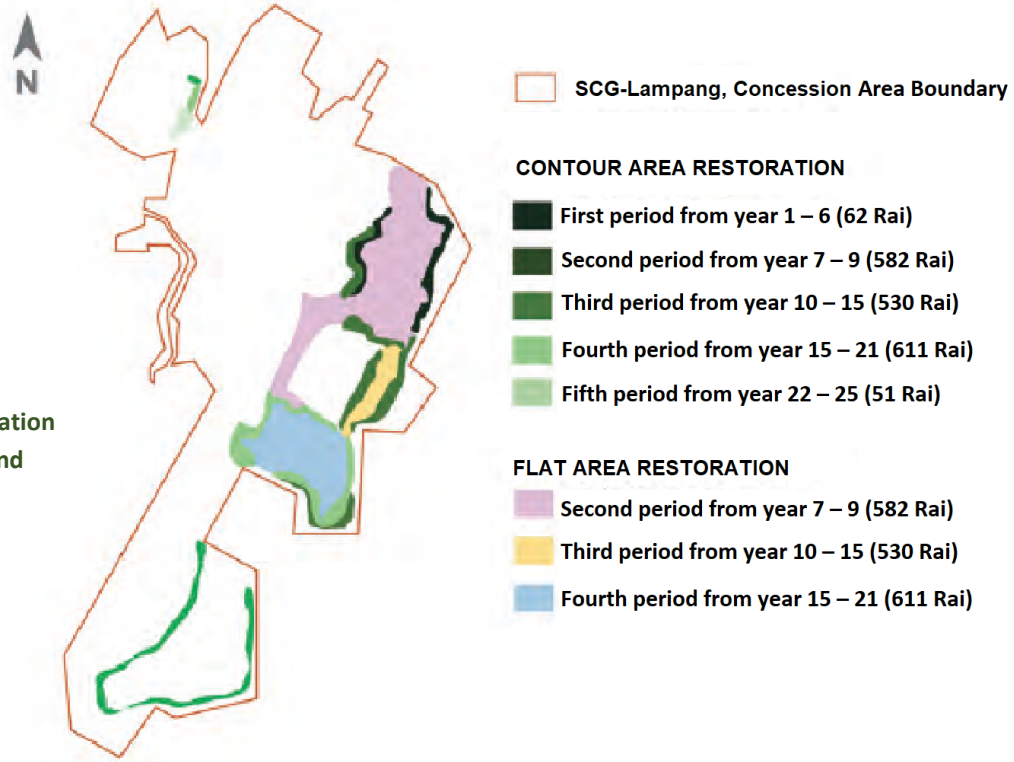


Figure 1.14 - Classification of restoration area and period of time.

The latest policy of the mine in 2018 (Declaration No.1/2018) (SCG, 2018b) provides a road map towards achieving a net positive impact on the environment by following international standards of quarry operation and by establishing a "**Framework for Quarry Rehabilitation**

and Biodiversity Management". The goal is to restore forest ecosystems to support and enhancing recovery of biodiversity and provide for the conservation of both plant and animal species.

This framework is being implemented in 3 phases (Table 1.3) (CCOP, 2018), under the supervision of **The Quarry Rehabilitation Committee of SCG** – an established collaboration among multiple organizations to implement and monitor works under the framework. The work follows guidance provided by the World Business Council for Sustainable Development - Cement Sustainability Initiative (WBCSD CSI).

The "**Quarry Rehabilitation Report**" details the results, knowledge and lessons learn from the rehabilitation actions (SCG, 2017). It is being used to develop a long-term Biodiversity Management Plan, with the purpose of operationalizing actions towards rehabilitating the forest habitat to be comparable to natural forest in the buffer zone, with a similarity index of >60%.

Table 1.3 – Summary of the Mine Rehabilitation and Biodiversity Conservation Framework (Adapted from CCOP, 2018)

	Phase-1	Phase-2	Phase 3
Quarry rehabilitation	Quarry reclamation using fast growing species	Establish the Quarry Rehabilitation Committee of SCG Rehabilitation Master Plan Rehabilitation and Biodiversity policy Plant selection: Local plant survey	Forest restoration using Framework spices method Set up Rehabilitation Learning Centre (seedlings preparation) Rehabilitation report and handbook Dissemination of knowledge and collaborating with multi-stakeholders
Biodiversity management	The survey and baseline study on biodiversity (Flora and Fauna)	Applied the World Wildlife Fund (WWF) Mining and Biodiversity Guideline	Set up **Biodiversity Management Plan (BMP)** **Biodiversity offsetting** Ecosystem Services Review

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2 BIODIVERSITY – HABITATS & SPECIES

The SCG- Lampang mine is a mining concession located in the reserved forest (National Reserved Forests Act B.E.2507 (A.D.1964)) adjacent to Thum Pah Thai National Park.

Bamboo-deciduous Forest (formerly teak forest) is the main biodiversity habitat on the mine.

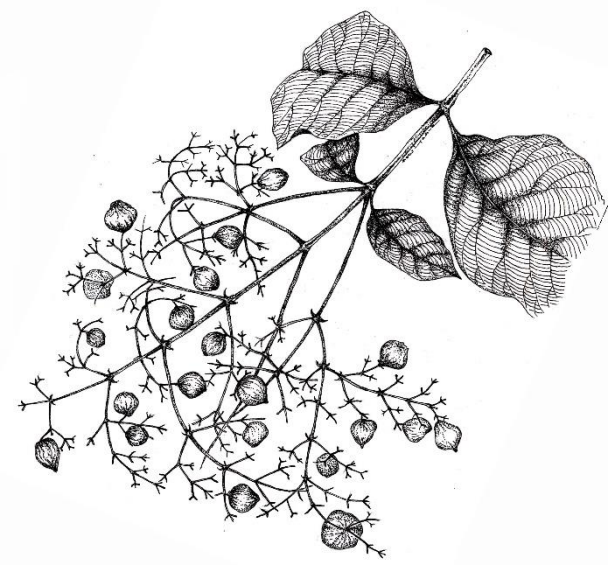
The mine lies within the lowland deciduous forest zone (from 350 m up), which now supports mostly **bamboo-deciduous forest** (BB/DF) formerly teak forest (*sensu* Maxwell and Elliott, 2001).

Originally, most of the region, up to about 900 m elevation, would have supported teak (*Tectona grandis*) forest (Fig. 2.1). However, most of the teak trees were logged from the late 19th century onwards, resulting in the BB/DF, which occupies most of the conservation zones in the mine concession area today. Although such logged-over forest is considered to be "degraded", removal of the dominant teak trees has enabled many of the rarer, less commercially valuable, tree species that are associated with teak, to proliferate, resulting in forest with high biodiversity.

Prevention of fire and encroachment is allowing the forest to regenerate.

In addition to logging, the forest would have been subjected to frequent fires and exploited for forest products prior to mine establishment. With the acquisition of the area by SCG, both fire and other human disturbances have been more restricted and forests in the conservation zones of the mine concession area are showing signs of natural regeneration, to such an extent that teak is once again prominent in the upper canopy in some areas. Fire prevention, in particular, has enabled survival and establishment of a wide range of both deciduous and evergreen forest tree species. Conservation of such forest is a high priority, both to maintain biodiversity at the site level and to provide tree seeds of local provenances to the forest restoration program on the mined areas.

Figure 2.1 - Teak tree foliage and fruit (*Tectona grandis*)



2.1 VEGETATION AND FLORA

Surveys over 6 years generated detailed knowledge of the flora.

This account of the vegetation and flora within the SCG-Lampang mine concession area is derived from forest surveys carried out by the FORRU-CMU team from 2013 to 2019, using circular sample plots (5-m radius) and transects both in the conservation forest zone and in the Phase-2 mining zone, just before tree removal, prior to the commencement of site clearance, in 2019. In addition, a floral survey was conducted by botanist J.F. Maxwell in 2013-16, during which most of the plants present were identified to species level.

2.1.1 TEAK AND BB/DF FOREST

BB/DF replaces teak forest after logging.

Before the latter decades of the 19th century, much of northern Thailand's lowlands were covered by forests, dominated by teak (*Tectona grandis* L. f. (Verbenaceae)) from valley bottoms up to 900 m elevation. However, exploitation and international trade of this valuable timber tree changed the character of these forests. Although remnants of teak forest can still be found in a few national parks, wild teak has now become rather rare and the forests, where it was once dominant, have now been become occupied by other tree species and especially by bamboos. Such is the case at the SCG Lampang mine. Most of the forest, remaining within the concession area, is BB/DF a form of degraded teak forest. Since teak is becoming rare in other areas, conservation of the remnant teak trees, as valuable seed sources, for future forestry applications, is a priority.

Figure 2.2 - Photos of conservation forest canopy (near mine office), taken 80 m above the ground by drone, September 2018, showing contrasting bamboo-dominated and teak-dominated areas.

Top – forest canopy dominated by flowering teak trees (crowns dotted yellow).

Bottom - forest canopy dominated by bamboos (feathery foliage).

Parts of the bamboo-deciduous forest at the SCG mine are almost completely dominated by bamboos, interspersed with remnant teak trees, often growing from tree stumps, whilst in more mesic areas, bamboos are less dense, and a wider range of tree species can be found. In some areas, drone imagery shows a resurgence of teak in the main canopy (Fig. 2.2).

Bamboos dominate drier areas. Teak is returning to more mesic sites.

Forest canopy cover is patchy, becoming even sparser in the dry season, since most trees drop their leaves. Remnant teak trees (mostly coppicing trunks) and dominance of the understory by bamboos are both indicative of this forest type (Fig. 2.3). The more mesic areas support some shrubs. Woody climbers are common. A few epiphytic orchids and ferns grow on the trunks or main branches of the larger trees, although orchids are scarcer in the SCG area than would be expected in this forest type, probably due to collection for selling. The ground layer consists mostly of mixed herbs and grasses.

All plant habits are represented, except for epiphytes, which are sparser than expected.

2.1.2 FOREST STRUCTURE

In BB/DF, main canopy trees grow up to 20-30 m tall, but occasional emergents sometimes grow to 40 m, as can be seen by the massive *Protium serratum* tree at the start of the transect below (Fig 2.4). Although the profile diagram appears to show distinct layers in the canopy, crown density analysis (Fig. 2.5) shows that the bulk of the crown cover, in this remnant forest, occurs within the 4-6 m above ground, with no clear division (i.e., no minima or gaps) between the layers. The high density of understory tree crowns (contrasted with the sparser canopy cover of the main canopy and emergents) indicates long-term forest recovery, following logging of the larger trees and is most likely a consequence of reduced human disturbance and fire prevention, since SCG took over responsibility for managing the area.

Forest structure indicates recent vigorous regeneration.

Figure 2.3 – BB/DF forest along the approach road to the mine office. The large tree to the right is teak (*Tectona grandis*). The dense understorey is mostly bamboos.

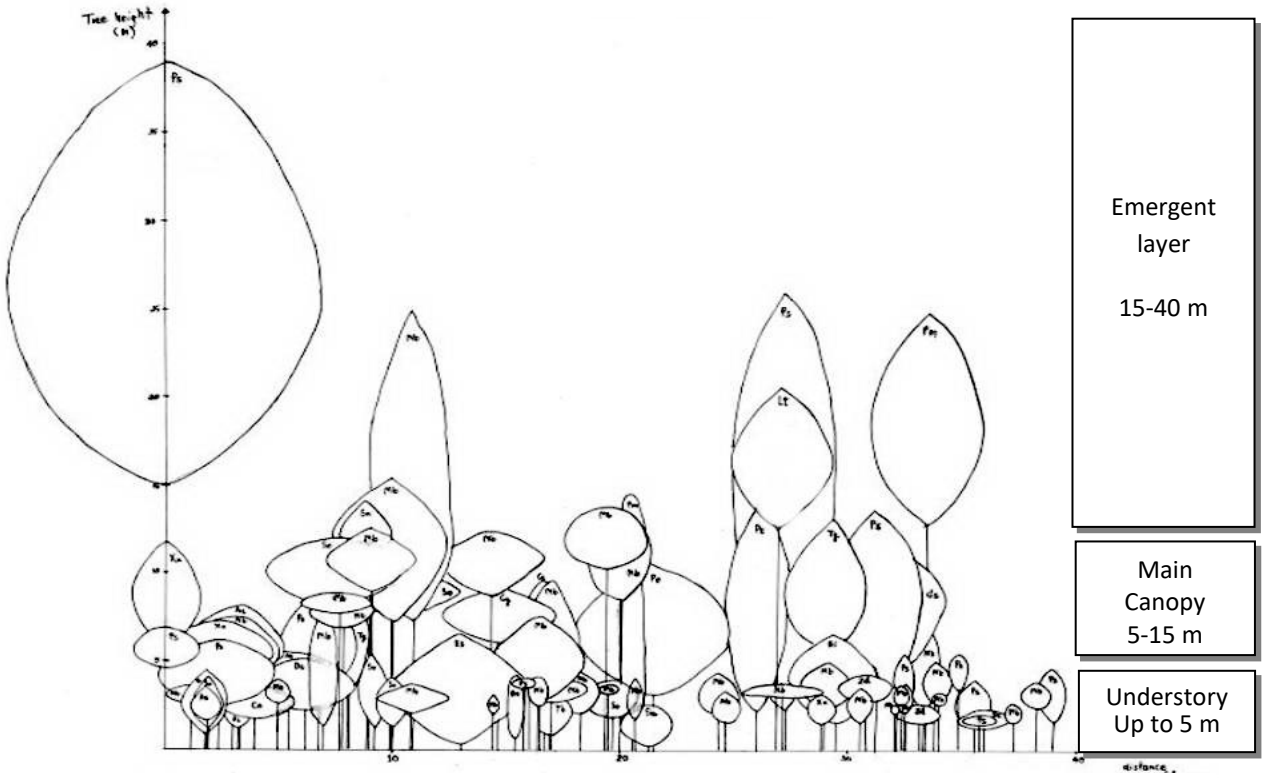


Figure 2.4 - Profile diagram through mesic BB/DF forest at the SCG Lampang mine near the mine office (bamboo not recorded): Ps, *Protium serratum*; Xx, *Xylia xylocarpa*; Po, *Polyalthia obtusa*; So, *Schleichera oleosa*; As, *Antidesma sootepensis*; Mb, *Millettia brandisiana*; Ce, *Clausnea excavata*; Dc, *Dalbergia cultrata*; Tg, *Tectona grandis*; Sn, *Stereospermum neuranthum*; Es, *Engelhardia spicata*; Cg, *Casearia grewiifollia*; Bv, *Bauhinia variegata;* Tb, *Terminalia bellirica*; Cs, *Canarium subulatum*; Pm, *Pterocarpus macrocarpa*; Sa, *Streblus asper*; Lt, *Lepisanthes tetraphylla*; Hi, *Holoptelea intergrifolia*; Zd, *Zollingeria dongnaiensis*; Gs, *Gardenia sootepensis*.

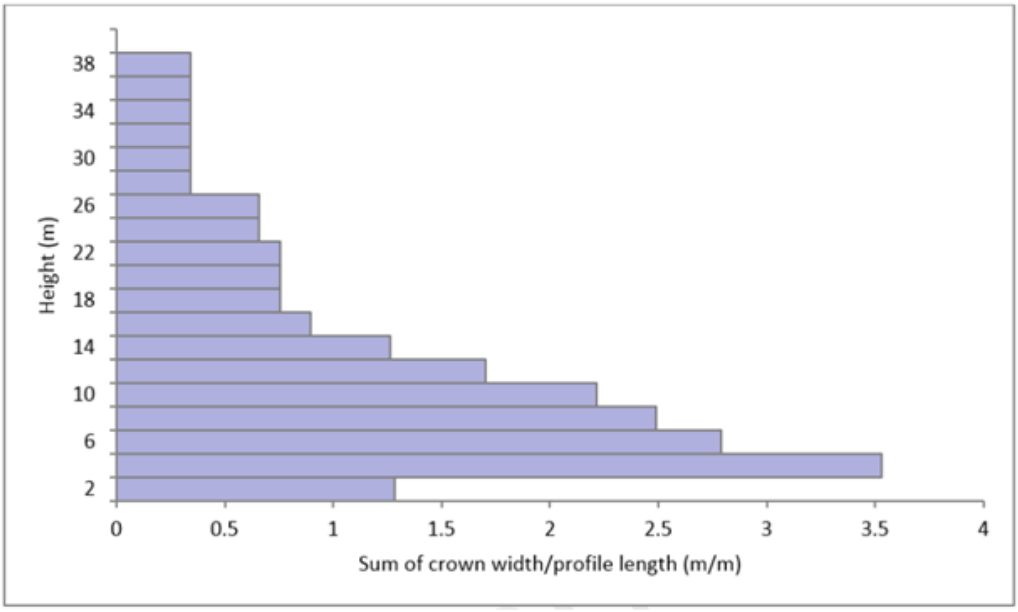


Figure 2.5 - Canopy density variation with height in BB/DF forest of the above transect

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Figure 2.6 - A mesic area of bamboo deciduous forest, showing high understory density, comprised mostly of tree saplings, which have grown up over 20 years since the area was protected, after incorporation into the mine area.

2.1.3 FLORA

The tree flora is dominated by three abundant species

The most abundant tree species was the deciduous *Millettia brandisiana* Kurz (Leguminosae, Papilionoideae), which accounted for about a quarter of all trees identified (Fig. 2.7). So, this species is approaching dominance. However, it was not recorded as seedlings in the ground flora, so it is expected that its dominance will decline in the future. *Protium serratum* (Wall. ex Colebr.) Engl. (Burseraceae), often growing to very large sizes (Fig. 2.7) and *Xylia xylocarpa* (Roxb.) Taub. var. *kerrii* (Craib & Hutch.) Niels. (Leguminosae, Mimosoideae), a highly valuable timber species, accounted for a further 10% of the trees each. So together, just these 3 species, represented nearly 35% of the trees examined in this study.

Figure 2.7 - *Millettia brandisiana* flowers (January) (left). *Protium serratum* fruits September (right).

The vast majority of tree species are locally rare.

The rest of the tree community comprises a large number of uncommon or rare species (Appendix 1). These include some valuable commercial tree species such as, *Dalbergia cultrata* Grah. ex Bth. var. *cultrata*, *Pterocarpus macrocarpus* Kurz (both Leguminosae, Papilionoideae), *Lagerstroemia cochinchinensis* (Lythraceae), *Chukrasia tabularis* A. Juss. (Meliaceae) and *Afzelia xylocarpa* (Kurz) Craib (Leguminosae, Caesalpinioideae). Previous logging has probably favoured other less valuable and more light-loving species such as *Terminalia chebula* Retz. var. *chebula*, *T. mucronata* Craib & Hutch. (Combretaceae) and *Sterculia villosa* Pierre (Sterculiaceae). Common understorey trees include: *Vitex canescens* Kurz and *Vitex peduncularis* Wall.ex Schaur (both Verbenaceae), *Cassia fistula* L. (Leguminosae, Caesalpinioideae), *Antidesma sootepense* Retz., *Phyllanthus emblica* L. (both Euphorbiaceae), *Stereospermum neuranthum* Kurz and *Oroxylum indicum* (L.) Kurz (both Bignoniaceae). Rarer deciduous trees include *Schleichera oleosa* (Lour.) Oken (Sapindaceae), *Hymenodictyon orixense* (Roxb.) Mabb. (Rubiaceae) and *Xantolis burmanica* (Coll. & Hemsl) Roy. (Sapotaceae).

Lack of secondary forest species indicates forest regeneration is advanced.

Secondary growth trees are few and scattered, again indicating advanced regeneration of the remaining forest. The more common species included *Gmelina arborea* Roxb. (Verbenaceae), *Oroxylum indica* (L.) Bth. ex Kurz and *Markhamia stipulata* (Wall. ex Seem.) K. Sch. (both Bignoniaceae), and *Mallotus philippensis* (Lmk.) M.A. (Euphorbiaceae). Tree stumps were commonly observed, giving an indication of what the forest must have been like pre-logging.

Woody climbers are less common than expected.

Woody climbers (lianas), often quite large, are usually a notable feature of this forest type, but are not well represented within the mine site. The most common species was *Congea tomentosa* Roxb. var. *tomentosa* (Verbenaceae); typical of BB/DF (Fig. 2.8).

Figure 2.8 - *Congea tomentosa* Roxb. var. tomentosa (Verbenaceae), the commonest liana in BB/DF. Its pink flowers are conspicuously draped over the forest canopy February to April, whilst the plant is leafless.

Figure 2.9 – Bamboos largely replace the shrub layer

Bamboos dominate the understorey

The shrub layer has been almost totally replaced by bamboos (Gramineae, Bambusoideae), over large areas of the remaining forest (Fig. 2.9). Abundant bamboo species, especially in the more disturbed areas, include *Bambusa membranacea* (Munro) Stap. & Xia, *B. tulda* Roxb., *Dendrocalamus nudus* Pilg., *Dendrocalamus strictus* and *Gigantochloa albociliata* (Munro) Munro. Elsewhere, the shrubs *Barleria cristata* L., (Acanthaceae), *Hymenopyramis brachiata* Wall. ex Schauer (Verbenaceae) and *Leea indica* (Burm. f.) Merr. (Vitaceae) are common.

Diverse ground flora is highly seasonal

The ground flora comprises at least 69 vascular plant species (Appendix 2), of which more than half (38) are tree seedling species. The ground is mostly bare during the dry season (November-April). The first herbs to appear are gingers (e.g. *Zingiber bradleyanum* Craib (Zingiberaceae)) and orchids, but the latter are very rare in the mine area, probably due to over-collection. One of the more striking herbs is *Amorphophallus macrorhizus* Craib (Araceae)) (Fig. 2.10), which flowers in April, before its leaves appear (outside our sample plots). By about July, many other herbs have matured, including many fern allies, e.g. *Selaginella ostenfeldii* Hier. (Selaginellaceae).

Figure 2.10 - *Amorphophallus macrorhizus*, fruiting in May

Some herbaceous weeds persist.

Light-loving grasses (*Oryza meyeriana* (Zollinger & Moritzi) Baillon (wild rice), *Pennisetum polystachyon* (L.) Schult. and *Phragmites vallatoria* (Pluk. ex L.) J.F. Veldkamp (all Gramineae) and weedy species of the family Compositae (e.g., *Bidens pilosa* L. and *Chromolaena odorata* (L.) King & H.E. Robins.) remain common in the ground flora, indicating incomplete tree canopy closure and patches of high light intensity at ground level.

SCG-Lampang site supports >70% of total BB/DF flora …

At least 173 tree species have been recorded in BB/DF in northern Thailand (Maxwell and Elliott, 2001), of which 127 (or 73%) were recorded during flora surveys in the same forest type at the SCG Lampang mine area (Appendix 1). Although 13 tree species were recorded only as seedlings in the ground flora, it is assumed that the adult trees, from which they were derived, must be located somewhere in or nearby the mine site (though not found within the sample plots). This increased the number of recorded forest tree species on the mine site by 51, compared with the Baseline Biodiversity Report (which recorded only 76 species) (WWF & SCG, 2009).

… but the ground flora is species-poor.

Of the 398 herb or vine species, known to grow in BB/DF, only 17 (4%) were found during the floral survey of the mine (Appendix 2), indicating a highly-impoverished ground flora. This may be due to:

i) the lingering effects of previous fires,
ii) overdominance of bamboos,
iii) spread of invasive species,
iv) limited dispersal capabilities of ground herbs and/or
v) over-collection of the showier species especially orchids.

This means that, despite a previous history of heavy disturbance, the areas of the mine that are currently under forest, support a diverse and regenerating tree flora, but lack the rich ground flora, typical of BB/DF. Consequently, both floral diversity and animal diversity (via the food web), particularly insects, could be enhanced by the re-introduction of herbaceous species, particularly orchids, which were not recorded at all in the survey sample plots.

2.1.3 INVASIVE EXOTIC PLANT SPECIES

L. leucocephala threatens biodiversity and forest restoration.

Leucaena leucocephala (Lmk.) De Wit (Leguminosae, Mimosoideae) and to a lesser extent *Delonix regia* (Boj. ex Hk.) Raf. (Leguminosae, Caesalpinoideae) (Fig. 2.11) are both invasive exotic species, which have been planted along the roads around the mine. Not only are these species spreading into remnant forest, smothering the indigenous species, they also threaten the viability of forest restoration on the mine site by competing with planted tree saplings (Fig. 2.11). Seeds of *L. leucocephala* are transported along roads into the pit area by incoming traffic, where they germinate, resulting in dominance of the species around the pit rim. From there, seeds invade the forest restoration sites and the emergent *L. leucocephala* saplings overgrow and smother the planted trees, in some cases leading to total failure of some restoration plots. This is a problem, not just at the Lampang mine site, but also in other mine sites, where *L. leucocephala* was planted to accelerate greening operations.

The complete removal of *L. leucocephala,* not only from the mine site, but also from the roads leading to the mine is seen as a top priority, essential to biodiversity recovery in conservation zones and to the success of forest restoration.

Figure 2.11 - Left: seed pods of *D. regia*. Centre: seed pods of *L. leucocephala*, along a road into the mine. Right: *L. leucocephala* seedlings invading restoration site.

2.2 BIRDS

Diverse but otherwise unremarkable bird community

A total of 176 bird species have been recorded within the mine concession area. All are ranked by the International Union for Conservation of Nature as species of "least concern" globally. Since birds are easily observed and Thailand is a popular destination for bird watchers the bird community provides attractive components for environmental education activities.

2.3 MAMMALS

Mammal community, functionally intact but contains several species of conservation concern.

A total of 33 mammal species have been recorded within the mine concession area, during 4 surveys, including camera trapping. Since bats are the most specious group of mammals in South East Asian forests and are represented at the mine by one insectivorous species (*Rhinolophus yunnanensis*) and one frugivore (*Cynopterus brachyotis*) (both of least concern). It is very likely that many other species, are present, probably including additional fruit bats, which are important seed dispersers that support recovery of tree-species richness during forest restoration. Other mammal groups include primates, rodents, ungulates, civets and mustelids, sufficiently diverse to support ecosystem functionality.

Of particular interest is the presence of three monkey species in the concession area: the Assamese macaque (*Macaca assamensis*; near threatened), the southern pig-tailed macaque (*Macaca nemestrina*; vulnerable) and the rhesus monkey (*Macaca mulatta*; least concern). Habitat conservation and protection as well as excluding hunters will be vital for the protection of these species all of which are important seed-dispersers that support forest restoration.

Figure 2.12 – breeding pig tailed macaques feeding on planted fig trees in a restoration plot on pit 1.

Several other species are of conservation concern. The Sunda Pengolin (*Manis javanica*) is critically endangered and its population is declining rapidly, mostly as a result of hunting for trade in its scales, which are used in traditional medicine. In addition to habitat protection, the survival of this species depends on excluding hunters from the area. The Bengal Slow Loris (*Nycticebus bengalensis)* is endangered. The main threat is collection for the pet trade. The hog badger (*Arctonyx collaris*) is ranked as vulnerable mostly due to habitat loss.

Figure 2.13 – species of conservation concern – slow loris, pangolin and hog badger.

2.4 REPTILES AND AMPHIBIANS

Previous biodiversity surveys at the mine have revealed the presence of at least 36 reptile species and 15 amphibian species. None of the amphibian species are particularly rare but the reptiles include several spectacular rare species.

Rare reptiles —a major opportunity for conservation

Five of the reptiles are of conservation concern (Fig. 2.15), including 3 tortoises: the critically endangered elongated tortoise (*Indotestudo elongata*), the endangered impressed tortoise (*Manouria impressa*) and the Mekong snail-eating terrapin (*Malayemys subtrijuga*). The two tortoises feed on leaves, flowers, fungi, fruit, and slugs amongst the leaf litter of deciduous forests. The terrapin also requires aquatic habitats and feed on aquatic snails. They are threatened by habitat destruction, including fire, as well as collection for both the pet trade and as exotic food in some areas. The presence of such easy-to-collect species within the mine concession area is evidence of the effectiveness of the mine's security system in excluding hunters.

The yellow monitor (*Varanus flavescens*) is another endangered species, which is dependent on wet marshy areas for much of the year. It is carnivorous. It is threatened by drainage of wetlands and hunting, as it is eaten and its skin is traded internationally.

The King Cobra (*Ophiophagus hannah*) (Fig. 2.14) is rated as vulnerable and is present in the bamboo-dominated areas of the concession. Although more tolerant of habitat destruction compared with the other reptiles of the mine, it is hunted as food and for its skin and persecuted because it is highly venomous. Again, its presence on the mine is indicated the effectiveness of the mine's security system.

Figure 2.14 – king cobra - vulnerable

Figure 2.15 – reptile species of conservation concern, from top left clockwise: elongated tortoise, impressed tortoise, Mekong snail-eating terrapin, yellow monitor lizard (photos courtesy of IUCN and FORRU aerial phenology team).

2.5 AQUATIC HABITATS AND BIODIVERSITY

Aquatic habitats support non-aquatic biodiversity

The concession area located in the centre of the Wang watershed (Fig.1.12) and is ranked as an important watershed (classes 3 to 5). The aquatic habitats of the mine are critical for maintaining amphibian diversity and at least 2 of the rare reptile species (the yellow monitor and the Mekong snail-eating terrapin). Most aquatic habitats lie outside the immediate vicinity of the pit areas and their distribution is shown in Fig 2.16. Of prime importance is the stream that runs through the conservation forest areas, which has been widened into small ponds in several places. Most of the wildlife probably depends on this stream for drinking water. Shallow inlets of the Kiew Lom reservoir along the northern boundary of the concession area are also probably prime habitat for the yellow monitor and the Mekong terrapin.

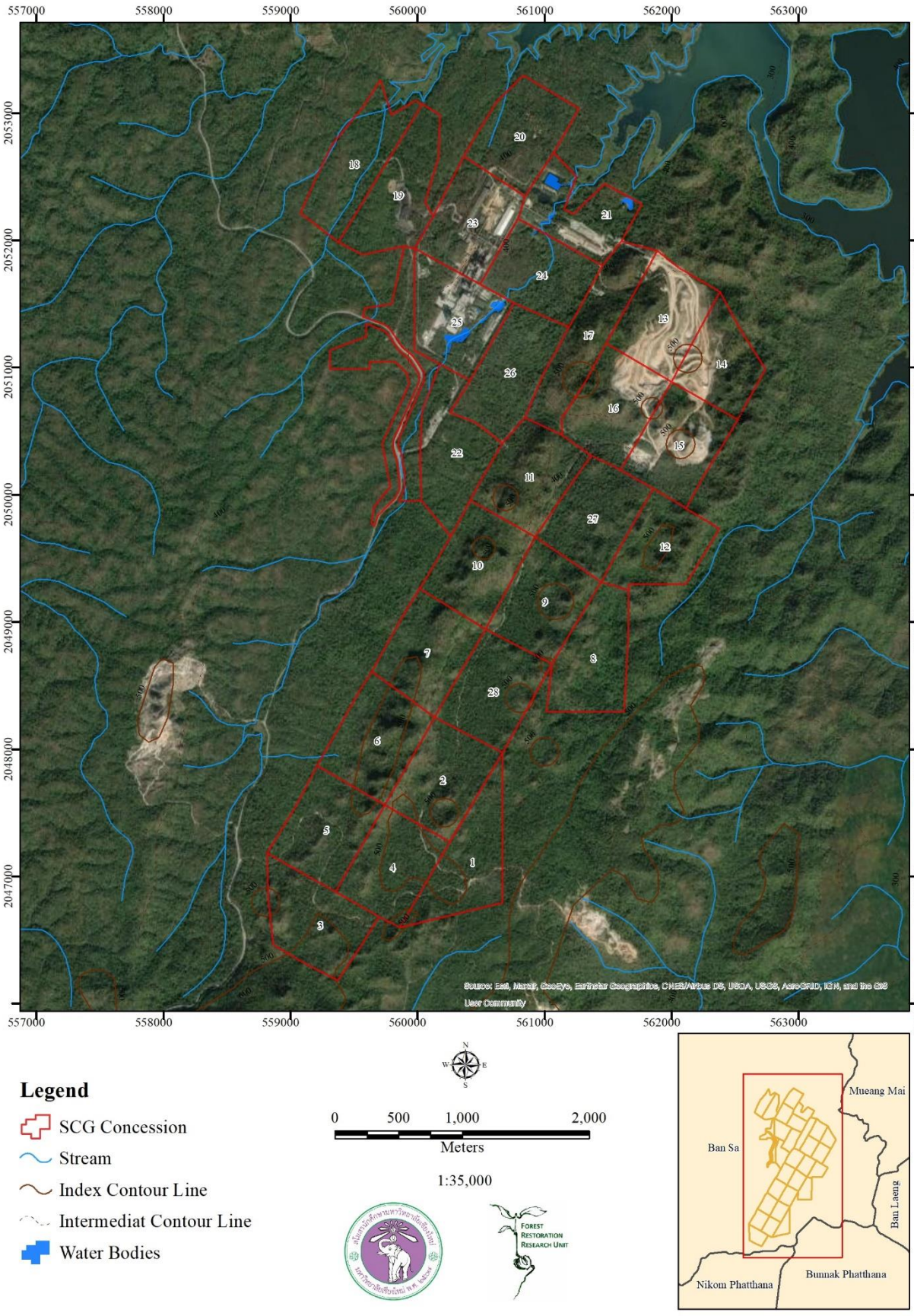

Figure 2.16 – aquatic habitats indicated by blue lines lie entirely outside the pit areas. Note the artificial ponds created along the stream tat runs through the conservation forest zone (NW).

Figure 2.17 – an artificial pond created along the stream that runs through the conservation forest – provides habitat for amphibians and terrapins and supplies drink water to other wildlife.

A survey of aquatic plants along the stream through the conservation forest to the inlet of the Kiew Lom reservoir recorded only 11 aquatic plant species, all fairly common: *Nymphaea lotus* L., *Ipomoea aquatica* Forssk., *Alternanthera sessilis* (L.) R. Br. ex DC, *Persicaria barbata* (L.) H.Hara, *Utricularia aurea* Lour., *Typha angustifolia* L., *Lemna aequinoctialis* Welw., *Spirodela polyrrhiza* (L.) Schleid., *Justicia* sp., *Eichhornia crassipes* (Mart.) Solms and *Nymphaea nouchali* Burm.f.

The Kiew Lom reservoir is a well know local fishery in Lampang Province. The most common fish are cyprinids, followed by catfish, murrels, and various other species. Exotic species, such as Chinese and Indian Carp and Nile Tilapia are also present.

The Fisheries Department carries out stock enhancement in the reservoir annually. Since the early 1990s, stocking programs have shifted from exotics to indigenous species such as: silver barb (*Barbonymus gonionotus*), seven-line barb *(Probarbus jullieni*), broad-head walking catfish (*Clarias macrocephalus*), common Siamese barb (*Henicorhynchus siamensis*), iridescent shark catfish (*Pangasianodon hypophthalmus*), tinfoil barb (*Barbodes schwanenfeldi*), golden barb (*Barbonymus altus*), black eye shark catfish (*Pangasius larnaudii*) and tiny scale barb (*Thynnichthys thynnoides*). Stocking is done to provide benefits to nearby rural communities. Since fishing is for subsistence (rather than for commercial exploitation) the fish communities and the aquatic ecosystem generally are not considered to be threatened by local fishing activities.

Other aquatic animal species, such as freshwater crab, prawn, shrimp, and clam have been reported in the Wang watershed. Forty-two species have been reported: 9 species of freshwater prawn/shrimp, 3 crab species, 14 bivalves & 16 aquatic snails. Two freshwater pearl mussels are of high economic value: *Hyriopsis myersiana* (LC) and *Chamberlainia hainesiana* (DD).

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3 IMPACT OF MINING OPERATIONS ON BIODIVERSITY

3.1 HABITAT LOSS

3.1.1 FORESTS

Open-cast mining inevitably completely destroys natural habitats such as forest ecosystems. However, the area, affected by such damage should be minimized. Furthermore, following mine closure, forest should be restored to pit areas or, if that proves impossible, restored to degraded areas outside the mine in compensation (biodiversity offset). The forest reserve area, around the mine concession, is part of **Mae Sai Kham Forest Reserve** under the Royal Forest Department. At the start of the mine operations, during the 1990s, the forest had already been degraded by the removal of valuable timber species including *Dipterocarpus*, *Dalbergia* (Rosewood), *Tectona* (Teak) and *Xylia*.

60% of the concession area will remain undisturbed forest

The SCG used to mitigate habitat destruction by translocate the tree from the mine site to plant at adjacent site with additional tree planting to increase the maximum number of trees (Sal Forest, 2014). With SCG's Green Mining Model approach, 60% of the concession area are as '**Buffer zone** where the forest area approved by Royal Forest Department are left untouched (Fig, 3.1). However, to restore the natural condition such as biodiversity and ecosystem services at mining sites, additional input is needed, for example, assisted restoration aims at speeding up the natural regeneration of the ecosystem that may not always bring back the original ecosystem but an outcome that is considered meet the target of the restoration.

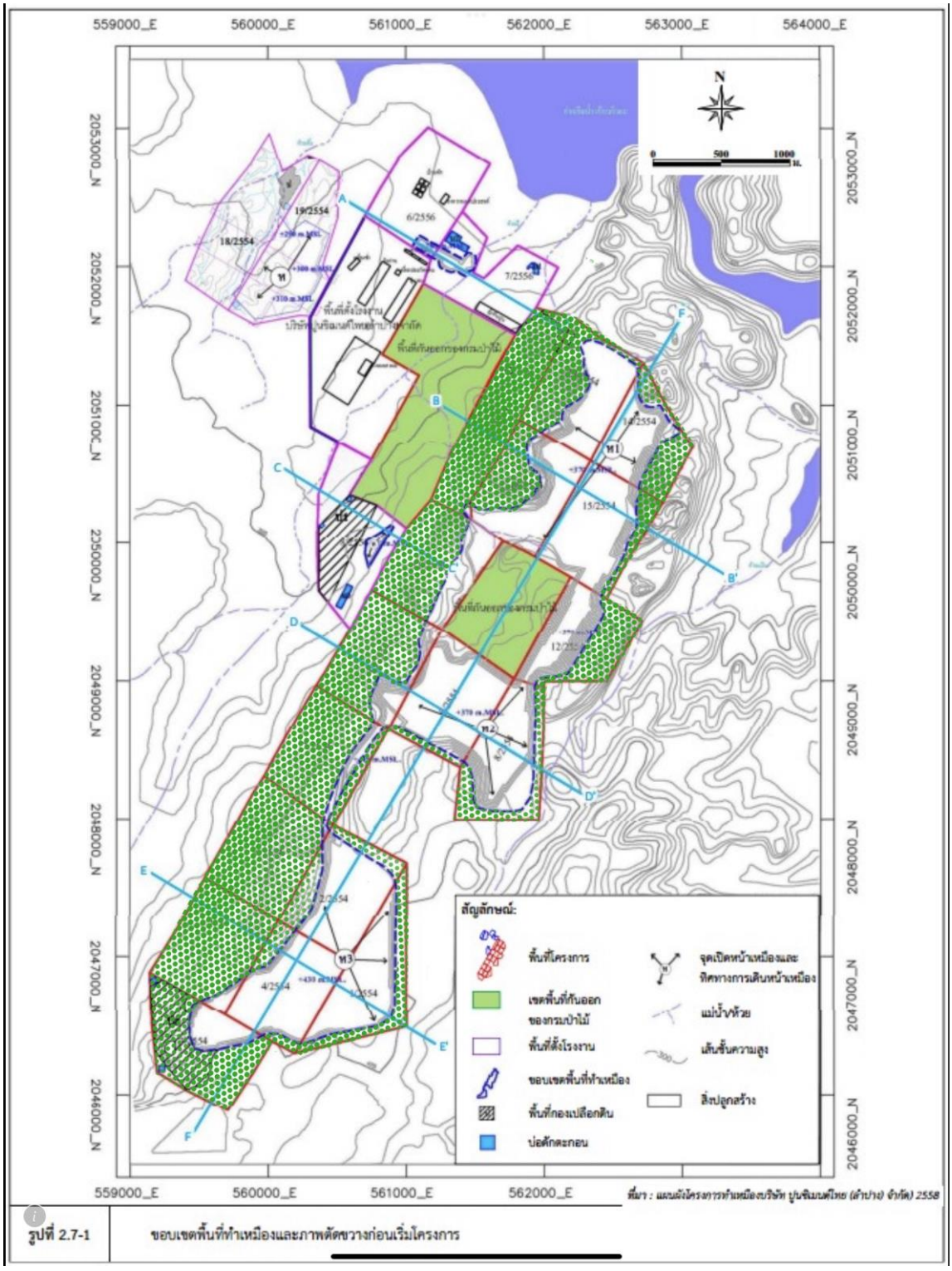

Figure 3.1 Forest Area left as the buffer zone and conserved forest issued by the Royal Forest Department

3.2 POLLUTION

3.2.1 DUST

Dust and noise in the factory and two nearby communities doesnot currently exceed standard levels set by the National Environment Board.

During the mining process, water is sprayed onto the raw materials, storage areas and along transportation routes to reduce the spreading of dust 3 times a day. Dust collectors are installed and attached to the mine-drilling vehicles to prevent the dispersion of dust (Fig. 3.2). Tree such as *Pterocarpus macrocarpus* (Pradoo) and *Markhamia stipulata* (Khae Hang Khang) have been planted along the transportation routes to trap the dust. In the surrounding manufacturing process outside the mine pit, electrostatic precipitators and bag filters have been installed with preventive maintenance plans and closed transportation systems were put in place to control dust. For the air quality, measurement using "The Continuous Emission Monitoring Systems (CEMS)" has been installed at every smokestack to observe the emitted air. Mobile cars with sensors have been deployed to monitor air quality around the plant. Environmental laboratories have been set up to investigate and prevent environmental impacts from mining operations (SCG, 2012). The dust measurement in April 2019 reveal that the particulate matter (PM10) measured in the factory area and in 2 communities surrounding the concession area does not exceed the ambient air quality standard level issued by the National Environment Board (PCD, 2004) with a mean PM10 in 24 hrs., between 0.037-0.094 mg/m^3 (standard level ≤ 0.12 mg/m^3)

Figure 3.2 The dust collector on the drilling machine

3.2.2 NOISE

To monitor the noise impact from mining operation (mainly from blasting, transportation and factory processes), Integrated Sound Level Meters have been installed in the factory areas and in 2 nearby the concession area (Fig. 3.3). The latest noise measurement in April 2019 revealed that equivalent sound level (Leq) every 1 hour (Leq 1 hrs.), every 24 hour (Leq 24 hrs.) and maximum (Lomax) in 3 measuring stations are in the standard level according to the standard of Noise and Vibration from the mine operation (MonRE, 2005).

Figure 3.3 Sound Level Meter used to measure noise in the community area

3.2.3 WATER QUALITY

Six water sampling sites were analyzed to keep track on water quality parameters for the surface water in the reservoir, streams and water for household consumption.

The preventive and mitigation measure from the EIA first issuing concession in 1992 report designated three sampling spots in the reservoir to collect water quality data twice a year (rainy and dry season) (ONEP, 1992). The Semi-Open Cut Mining approach is minimizing the impact on the water infrastructure by not opening the pits down to the depth of 280 meters, which is the lowest depth of the Kiew Lom Reservoir, to prevent water leaking into the pits (Sal Forest, 2014). Rainwater is used for mine operations, stored in reservoirs near

the factory. A wastewater treatment system has been established, to reduce risks to quality and quantity of water discharged from the mine.

During 19-20 July 2018, water samples were collected from 6 sites to measure the surface water quality (Fig. 3.4) and 3 sites at the outlets of three streams into the Kiew Lom Reservoir (W1, W2, W3). Other sampling (W4) from the last sediment trap in SCG Lampang factory, Water well (W5) which store water from Huai Poo and Huai poo (W6) before entering the SCG Lampang factory. One additional site to measure water quality for household consumption was collected from water tank in Ban Sam Phao Thong (W7). The variables measured were: pH, turbidity, suspended solids (SS), total dissolved solid (TDS), total hardness, sulfate, total iron, lead, cadmium and arsenic. The results from At W1-6 all variables did not exceed the standard approved by the National Environment Board issue 8/1994 (Surface Water Quality standard). For W7 all parameters not exceed the standard approve by the Ministry of Industry issue 3470/2008 (Drinking-water Quality) except for the Total Hardness (SCI eco services, 2019).

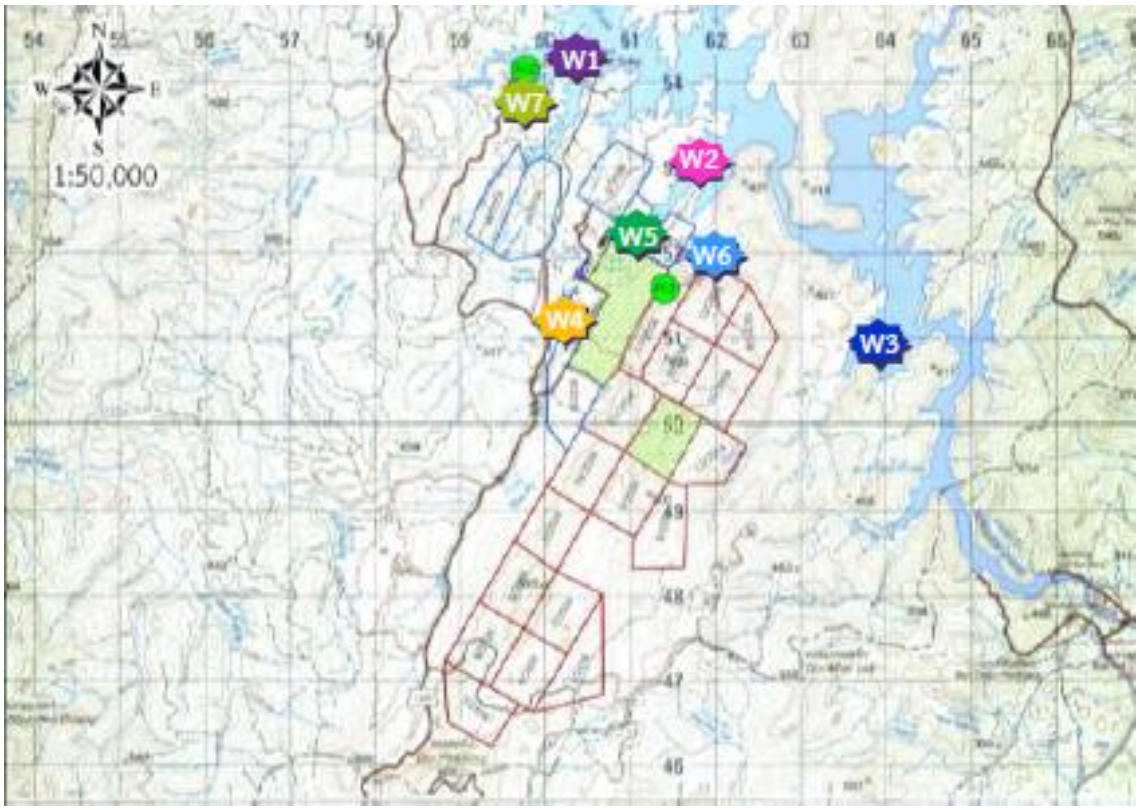

Figure 3.4 All water quality sampling sites

3.3 INVASIVE SPECIES

Invasive Alien Species was found in the area where SCG, RFD and communities collaborate to eliminate the identified species as a threat to biodiversity

Spread of invasive species through mining is considered as an environmental threat where the single species could overrun through the mined landscape and become a barrier for mine restoration. In SCG Lampang, **Horse tamarind or in Thai "Kra-Thin"** ***Leucaena leucocephala*** (Fabaceae) a native of south-eastern Mexico, the species commonly cultivated as hedge plant but escaped as weed throughout Thailand (Fig. 3.5). The species can grow on a wide range of sites and soils which make it the most aggressive colonizer of degraded and disturbed sites and spreads naturally through seeds, which are produced in large numbers (Hughes, 1998). The species is coppiced vigorously which makes mechanical control through slashing has not been effective.

Figure 3.5 An invasive tree, *Leucaena leucocephala*

In 2013, SCG company carried out a collaborative survey with communities and the Royal Forestry Department in deciduous forest to identify the threat on biodiversity and indigenous plant including 2 Invasive Alien Species ***Lantana camara*** and ***Chromolaena odorata*** (Fig. 3.6, 3.7). In 2014-2017, elimination of alien invasive species was conducted in 0.352 km², in collaboration with communities to manage 0.08 km²per year (SCG, 2018).

Figure3-6 *Lantana camara*

Figure 3.7 *Chromolaena odorata*

3.4 FOREST PROTECTION

Forest protection maintain a value landscape and a source for rehabilitation for the mine with additional activities done by SCG, forestry officials and communities such as fire protection, building check dam

Since 1993, The Royal Forest Department has not allow any mine operation in the 4 plots on the less steep slope on the western part of the concession area as it have very high abundance of forest tree. The Royal Forest Department has issued the preventive measure *"Prohibit of mining and explosive operation which can be seen from highway number 1035 and create a gap away from the road along the edge of the Kiew Lom Reservoir*" In the present day, this area is in the concession No. 13/2011 and 16/2011 has been manage to maintain the natural landscape and use as a source of tree seed for quarry rehabilitation and also support research and education (SCI eco services, 2019) (Fig. 3.8).

Figure 3.8 Protected Forest plot together with the SCG Lampang factory

SCG Lampang supports forest protection activities such as forest fire protection during the dry season through CSR approach (Fig. 3.9). Building check dams to enhance humidity in forest are regularly done by providing fund and labour force. The public relation with the communities about rare animal and plant species that could be found around the concession area was done with support from the Protected Area Regional Office 13 (Lampang), Department of National Park

Wildlife and Plant Conservation whenever there is a crucial occasion to translocate the near-threaten and endangered species away from the mine operation. Ongoing collaboration between SCG, forestry officials and communities could maintain a strong relationship between groups and help prevent other threats to the natural resources especially an external illegal logger (Lampang's Provincial Executive meeting report, 2006).

Figure 3.9 SCG Lampang and villagers building check dam

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4 BIODIVERSITY MANAGEMENT PLAN OBJECTIVES

Biological diversity (also known as biodiversity) can be defined as "the variety of life on Earth at all its levels, from genes to ecosystems, and the ecological and evolutionary processes that sustain it." It encompasses not only different animal and plant species and the habitats in which they live, but also "ecosystem services", such as carbon storage, watershed services provision of forest products and pollination upon which human wellbeing depends.

Biodiversity is the variety of life on Earth.

The region in which the SCG Lampang mine is located is recognised and valued for its high biodiversity, because it is located at the juncture of 3 distinct biogeographical regions (Himalayan, Indochinese and Sundaic). Consequently, the distributions of many species of flora and fauna, representative of all 3 regions, overlap at this point, resulting in high biodiversity.

The mine is in an area of high biodiversity.

Therefore, it is important that proactive and coordinated management is implemented, involving all stakeholders. Consequently, this BMP has been formulated to set a strategic context, as well as detail on-the-ground management, research and monitoring activities, which should be implemented, to ensure that SCG makes a positive contribution to the management and preservation of biodiversity in and around the Lampang mine (Fig. 4.1).

This report details the management needed to conserve this high biodiversity.

Figure 4.1 - SCG staff monitoring biodiversity at the Lampang mine.

4.1 LINKS WITH GLOBAL AND NATIONAL BIODIVERSITY POLICIES

This BMP assists SCG to contribute towards national biodiversity objectives and helps Thailand to meet its global commitments under the CBD.

Thailand ratified the Convention on Biodiversity in January 2004. As part of Thailand's obligations under the CBD, the Office of Environmental Policy and Planning developed a "Master Plan for Integrated Biodiversity Management (2015-2021)" (Thailand's 4th NBSAP document), which was adopted by Cabinet on 10 March 2015. The vision of the plan is that by 2021, "people live in harmony with nature, and the government, along with all other sectors, promotes and supports the protection, conservation and sustainable utilization of biodiversity. Two main missions are stated:

i) integrate management for the protection, restoration and utilization of biodiversity efficiently through participation at all levels, to halt biodiversity loss and
ii) increase policy and management importance and raise social awareness about the roles and importance of biodiversity to support sustainable development and the green economy.

More specific objectives are:

i) address the underlying causes of biodiversity loss by mainstreaming biodiversity across public and civil society sectors;
ii) reduce direct pressures on biodiversity and promote the sustainable use of biodiversity;
iii) improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity;
iv) enable management to enhance the benefits from biodiversity and ecosystem services and
v) enhance management and implementation of biodiversity-related obligations, through participatory planning, knowledge management and capacity-building.

The private sector is one of 5 sectors identified in the management plan as relevant to Thailand's biodiversity management (the others are the public sector, NGO's, local communities and the research community). As one of the largest and leading private-sector

corporations in the country, SCG is therefore obliged to contribute responsibly towards the achievement of national biodiversity objectives and help to fulfil Thailand's global commitments under the CBD.

The BMP, presented, here contributes towards several of the major targets identified in the master plan including: increased participation of every sector of society in the conservation, restoration and sustainable use of biodiversity; integration of biodiversity in relevant policies and plans at all levels; implementation of measures for managing invasive alien species and mobilization of biodiversity management with participation at all levels.

4.2 REQUIREMENTS OF THE BMP

As a partner of the World Business Council for Sustainable Development's Cement Sustainability Initiative (WBCSD-CSI), SCG recognises that conservation and responsible management of biodiversity are a response to both changing societal expectations and our understanding of business values.

SCG has launched its Environmental and Energy Policy in 2016, to enhance efficient and effective implementation in all areas of SCG operations. In 2017, SCG's Biodiversity Committee was set up, to control biodiversity conservation actions in accordance with international standards for biological resources management and to facilitate collaborate with all stakeholders under the concept "Business, Community and Environment living together sustainably" and "Net Positive Impact".

SCG's policies are in line with international guidelines.

The goals of environmental management are:

i) All SCG limestone mines in Thailand should develop a Mine-Closure Plan and Biodiversity Management Plan,
ii) Similarity of Biodiversity (Similarity Index) between Restoration Areas and Buffer Zones is higher than 60% and
iii) Forest Stewardship Council (FSC) certification of 10% of two Forest Parks (Kanchanaburi and Khampeng Petch, 25,000 rai).

4.3 AIM OF BMP

Forest in the buffer zone provides the target for ecological restoration – in terms of tree species diversity and composition.

To restore forest ecosystems similar to those present before mining commenced, particularly with respect to tree species richness (as the foundation of recovery of biomass, forest structure, niches for biodiversity recovery and ecological functioning). The mine's buffer zone provides the reference system, effectively defining the aims ecosystem for biodiversity management.

4.3.1 PRESERVE THE NATURAL ECOSYSTEMS OF THE BUFFER ZONE

Buffer zone provides a source of recolonizing plants and animals.

According to SCG policy, 50% of the concession area will remain as mature forest in the buffer zone, to reduce effects of mining on the surrounding area, whilst also conserving biodiversity and providing a source of seeds and recruit species to support biodiversity recovery in the restoration sites.

4.3.2 CONSERVE VULNERABLE FLORA AND FAUNA SPECIES

Conservation of biodiversity involves preventing the local extirpation of the rarest species of plants and animals.

4.3.3 RESTORE THE ECOSYSTEMS WITHIN THE CONCESSION AREA

Re-establishing original forest ecosystems.

On the pits and following dismantling of infrastructural elements, the plan aims to re-establish forest ecosystems on a trajectory towards those present before mining commenced, in terms of biomass, structural complexity, biodiversity of indicator species groups and ecological functioning, leading to the return of natural forest dynamics.

4.4 SPECIFIC OBJECTIVES

Sustainable management is at the core of SCG's principles—not only for business but also for the environment. The restoration of tropical forest ecosystems to their exact pre-disturbance species composition is not possible, due to climate change. Therefore, the objective of restoration becomes "*to direct and accelerate ecological succession towards an indigenous target forest ecosystem of the maximum biomass, structural complexity, biodiversity and ecological functioning*

that can be self-sustained within prevailing climatic and soil limitations." (Elliott et al., 2013)

4.3.1 INCREASE ECOSYSTEM BIOMASS

This is achieved by selecting tree species with high survival and growth rates when planted out in the harsh climatic conditions of mine sites where the substrate of compressed and lacks nutrients and micro-organisms. The objective is to achieve 80% seedling survival rate (over the first two years) and achieve 80% of the biomass levels of the reference forest within 20 years after tree planting.

Biomass >80% in 20 years

4.3.2 REBUILD STRUCTURAL COMPLEXITY

As biomass accumulates it can potentially be partitioned among more structural components: different tree architectures, climbers, epiphytes etc., all contributing to a multi-layered forest canopy. This objective is therefore to achieve the same number of canopy levels as the reference forest and 80% of the total canopy cover within 20 years.

Structure similar to reference forest in 20 years

4.3.3 RESTORE BIODIVERSITY

Increasing structural complexity creates an increasing variety of niches, which can potentially be re-colonized by an increasing diversity of plant and animal species; the driving force of biodiversity recovery. This objective is therefore to achieve diversity levels of indicator species groups (e.g., trees, ground flora and birds) of at least 60% of the level of the reference forest within 20 years.

Tree and bird diversity 60% of reference levels in 20 years

4.3.4 RE-ESTABLISH ECOSYSTEM FUNCTIONING

Forest restored on the pits should have similar ecological function as the reference forest, such as nutrient cycles and particularly the recovery of near-natural forest dynamics. This requires reconnecting mutualistic relationships, particularly between plants and their pollinators and seed dispersers; most tree species in the area are animal dispersed. Therefore, this objective to achieve leaf litter production, as well as organic matter and nutrients in upper soil layers, and numbers of tree species fruiting and establishing seedlings at levels 80% of those in reference forest within 20 years.

Soil nutrients and forest dynamics 80% of reference levels in 20 years

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5 AVOIDING OR MITIGATING HABITAT LOSS OR DEGRADATION

5.1 MAINTAIN SITE SECURITY, PREVENT ENCROACHMENT AND EXCLUDE LIVESTOCK

Maintain site security measures

Prolific forest regeneration and the presence of endangered, easily collected animals in the conservation and buffer forest (particularly the rare reptiles) are strong evidence that existing security measures are facilitating biodiversity recovery. This is probably due to the exclusion of local people, livestock and fire from the area.

Currently, the mine concession site is fenced, which effectively prevents intrusion by outsiders. Vehicles entering the site must pass through a security check point and present identification before being allowed on site. Although such measures are implemented primarily for safety purposes, their effect has also been to reduce forest degradation due to tree cutting and livestock browsing and trampling of tree seedlings, and to prevent hunting of animals and collection of plants. They have also effectively prevented setting of fires by local people inside the concession area. Consequently, even dangerous species, such as venomous snakes are relatively common within the concession area, whereas outside, they are harassed and decimated.

We, therefore, recommend that SCG continues or strengthens such security measures, during the working life of the mine, and, as mine closure approaches, works with the relevant authority to transfer responsibility for them accordingly.

Action points:

i) review mine security procedures at appropriate intervals and implement improvements when necessary, and

ii) inspect the security fences at appropriate intervals and carry out repairs where necessary

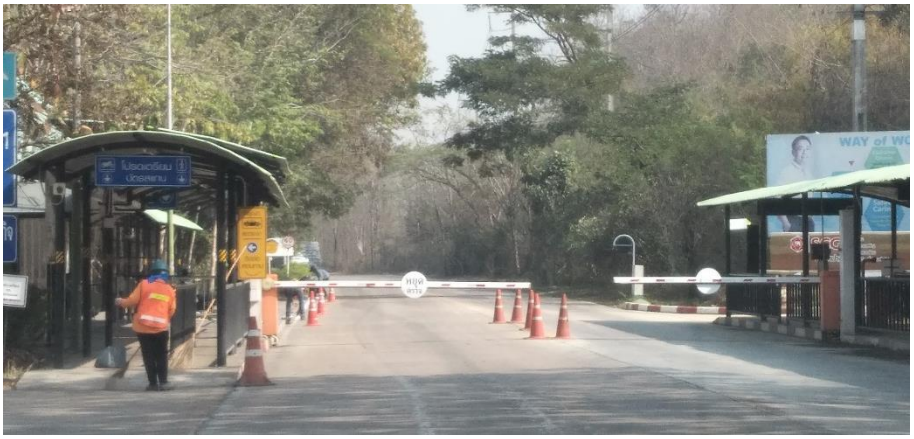


Figure 5.1 Maintaining controlled access and fencing are already contributing greatly to biodiversity conservation within the mine concession area and should be reviewed and improved

5.2 PREVENT FIRES

Implement comprehensive fire prevention and suppression measures.

Although existing security measures have prevented fire setting *within* the mining concession area, the probability of fires spreading into the conservation forest zones from outside is high. Consequently, we recommend the following: -

Action points:

i) Appoint an officer to monitor the occurrence of fires within 10 km of the mine, using NASA's Fire Information and Resource Management System (FIRMS) available free online[1] twice daily throughout the fire season, from mid-January till the first significant rainfall of the wet season and report fires moving towards the mine to senior staff, to alert and mobilize fire suppression crews.

ii) Maintain a fire tower in the centre of the largest preserved forest area, equipped with a drone, to track on-coming fires and co-ordinate fire-fighting as necessary. Appoint staff to man the tower during the fire season 24 h/day.

iii) Implement a messaging system to call into service a fire-fighting team when needed.

iv) Train and maintain a team of SCG staff, capable of safely tackling forest fires. Assign staff members to be "on-call" for fire suppression duties using a rota system throughout the fire season.

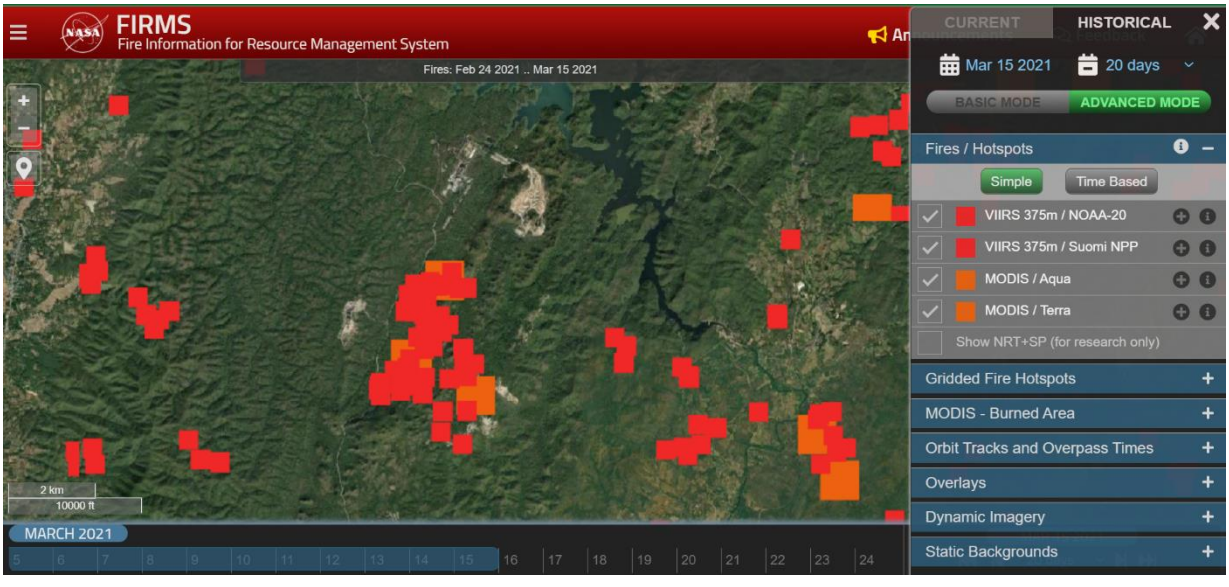


Figure 5.2 Active fires near the mine March 2021, using FIRMS. Such free web-based tools are recommended to allow cost effective management of fire suppression crews.

[1]Clicking on this link will open a map showing current fires around SCG's Lampang mine.
Fire Map - NASA | LANCE | FIRMS

v) Maintain a stash of fire-fighting equipment (beaters, spray tanks, masks etc.) on site and place barrels of water at strategic points around the conservation and buffer forest areas for rapid refilling of spray tanks, in advance of the fire season.
vi) Train and support train local people in fire prevention and fire fighting in neighbouring communities – to help prevent fires from reaching the mine area.

5.3 HABITAT CONSERVATION – PREVENT ANY FURTHER FOREST LOSS

Existing forest areas must be conserved to conserve biodiversity, support restoration and comply with the EIA.

According to the EIA, 59% of the concession is to remain forested, including areas labelled as buffer zone or conservation forests. Whilst this forest is not undisturbed primary forest, it is undergoing rapid regeneration, supports high biodiversity and has become inhabited by several rare and endangered species. Therefore, its maintenance is vital, not only as a repository of biodiversity, but also as a source of propagules for forest restoration where active mining has ceased. Consequently, apart from the forest clearance required to open up Pits 2 and 3, no further deforestation should be undertaken, both to comply with the EIA and maintain the aforementioned ecological functions.

Any habitat management actions should therefore aim to:

i) conserve existing biodiversity (particularly to prevent extirpation of rare species) and
ii) maintain a reservoir of plants (particularly seeds) and animals that can contribute towards achievement of ecological restoration goals in the mined areas.

Action points:

i) exclude external degrading factors by maintaining security and fire-prevention measures (see 5.1 & 5.3),
ii) reverse and prevent the invasion of forest areas by invasive exotic plant species (see 6.1).
iii) ensure that no further forest clearance is performed to establish mine buildings and/or infrastructure during the remaining phases of mine operation; place any such

infrastructure needed on former pit areas or where forest has already been cleared),

iv) annually verify the maintenance of existing forest cover, using satellite imagery or drones and

v) dredge artificial ponds (silt traps) periodically, to maintain aquatic habitats for amphibians and water supply for wildlife.

5.4 RESTORE FORESTS AND MAINTAIN AND INCREASE CONNECTIVITY AMONG FOREST PATCHES

Restore biomass, structure, biodiversity and functioning to original forest levels

SCG is legally required to restore forest ecosystem to the pits after mining ceases and to remove buildings and infrastructure from the concession area and to restore the sites, thus vacated, by re-establishing forest as similar as possible to that which existed before mining commenced. Although it is impossible to re-establish the original species composition of the original forest *exactly*, restoration can achieve the original "look and feel" of the original forest, such that plant and animal species recognize it as suitable habitat, thus conserving biodiversity. Therefore, the aim of restoration should be to "direct and accelerate ecological succession towards an indigenous target forest ecosystem of the maximum biomass, structural complexity, biodiversity and ecological functioning that can be self-sustained within prevailing climatic and soil limitations" (Elliott et al., 2013a) In this case, the target forest ecosystem is that described in Chapter 2.

Quantification of these goals as Key Performance Indices (KPI) are suggested as follows: -

i) Survival of planted trees exceeds 70% two years after planting.
ii) Tree biomass (including roots) on restoration plots exceeds 80% of that of conservation forest within 20 years.
iii) Number of canopy layers and distribution of canopy density (derived from profile diagrams (see Fig. 2.5)) equal that of a conservation forest within 25 years.
iv) Species richness of trees (>10-cm GBH) in restored plots equals that predicted by the species/area curve, derived from conservation forest, within 20 years (adjusted for the area of the restored plots)
v) Species richness of tree seedlings and saplings (>50 cm tall and <10 cm GBH) in restored plots equals that predicted by the species/area curve, derived from conservation forest, within 20 years (adjusted for the area of the restored plots)
vi) Total bird species richness (predicted from McKinnon's curves) in restored plots exceeds 75% of the same in conservation forest
vii) Levels of carbon and major plant nutrients (N, P, K) in the top 10 cm of soil in restoration plots exceeds 75% of the same in conservation forest.

Follow established forest restoration procedures and make better use of resources from forest clearance of subsequent pits.

Forest restoration, using the framework species method, has already begun on the first phase pit, as production there is winding down. Results have been generally accepted and monitoring has identified acceptable techniques and species choices. Therefore, it is recommended to continue with this approach, to complete restoration of forest cover on Pit 1 and to rehabilitate Pits 2 & 3 when the time comes. However, in the past, restoration work on the mine has failed to make good use of both on-site soil and propagule resources, therefore this should be rectified in future forest restoration initiatives:

Action points:

i) when clearing Pit 2, transfer top soil to forest restoration plots on Pit 1 (and from Pit 3 to Pit 2 subsequently)—to maintain soil seed bank, organic matter and microbes (Sansupa et al., 2021), during forest-restoration operations,

Conserve and make use of onsite sources of soils and propagules to maintain biodiversity in restoration plots.

ii) likewise transfer tree seeds/seedlings from Pit 2 to Pit 1 restoration plots (and from Pit 3 to Pit 2 subsequently),

iii) continue monthly phenology monitoring in buffer zone and conservation forest, to determine optimal seed-collection times and to provide seed-collection opportunities,

Continue with phenology studies and on-site nursery.

iv) continue to maintain an on-site tree nursery, to produce adequate quantities planting stocking of framework tree species from seeds collected from buffer zone and conservation forest and to handle propagules collected seeds and seedlings from clearance of Pits 2 & 3.

v) consider adding a seed bank to the nursery facility (or lodging seeds with the CMU seed bank) to store seeds in excess of current needs for future use,

vi) establish terraces (benches) as restoration plots in the pits (overall slope not higher than 45°), 3-5 meters wide to reduce erosion and landslide risk

vii) apply 100 cm of top soil,

viii) plant saplings (30-50 cm tall) of 20-30 framework tree species; 500/rai (1.8 m between trees), following standard procedures and using species previously recommended from field trials on the mine (Elliott et al., 2013b)

Follow restoration procedures already proven effective.

ix) apply compost, polymer gel, fertilizer (N:P:K; 15:15:15) and cardboard mulch mats when planting,

x) apply fertilizer and weeding, as needed, for at least two subsequent rainy seasons; water in dry season as feasible,

xi) position restoration plots to maximize connectivity, between existing and restored forest patches; particularly establish a corridor to link the preserved forest areas west of the mine offices to the block between Pits 1 and 2 and

xii) monitor growth and survival of planted trees and biodiversity recovery as outlined in Chapter 8.

Habitat connectivity is essential for the maintenance of biodiversity. It reduces the chances of isolated small populations becoming extirpated and it facilitates gene exchange and therefore, helps to

maintain genetic variability, which enables plant and animal species populations to survive environmental changes and disease outbreaks.

5.4.1 THE FRAMEWORK SPECIES METHOD

The framework species method harnesses the mechanisms of natural forest regeneration

The framework species method (Fig. 5.3) involves planting the fewest trees necessary to shade out weeds (i.e., site "re-capture") and attract seed-dispersing animals. In order for it to work, remnants of the target forest type must survive within a few kilometres of the restoration site (as a seed source). Animals, capable of dispersing seeds from remnant forest patches or isolated trees to restoration sites, must remain fairly common. The framework species method enhances this natural seed-dispersal service to achieve rapid tree species recruitment in restoration plots. Consequently, recovery of the biodiversity levels typical of climax forest ecosystems is attained without having to plant all the tree species that comprise the target forest ecosystem. In addition, the planted trees rapidly re-establish forest structure and functioning and create conditions on the forest floor that are conducive to germination of tree seeds and seedling establishment. Since SCG's northern limestone mines are largely surrounded by relative undisturbed natural forests, which support a variety of seed dispersing animal, the framework species approach is appropriate as a guiding concept for the restoration of such areas. The framework species method involves planting mixtures of 20-30 indigenous forest tree species, which are typical of the target forest ecosystem, but which also share the following ecological characteristics:

i) high survival when planted out in deforested sites,
ii) rapid growth,
iii) dense, spreading crowns that shade out herbaceous weeds and
iv) flowering, fruiting, or the provision of other resources, at a young age, which attract seed-dispersing wildlife.

A practical consideration is that framework species should be easy to propagate and, ideally, their seeds should germinate rapidly and synchronously, with subsequent growth of vigorous saplings to a plantable size (30-50 cm tall) in less than 1 year. Furthermore, where forest restoration must yield benefits to local communities, economic

criteria such as the productivity and value of products and ecological services, rendered by each species, may be taken into account.

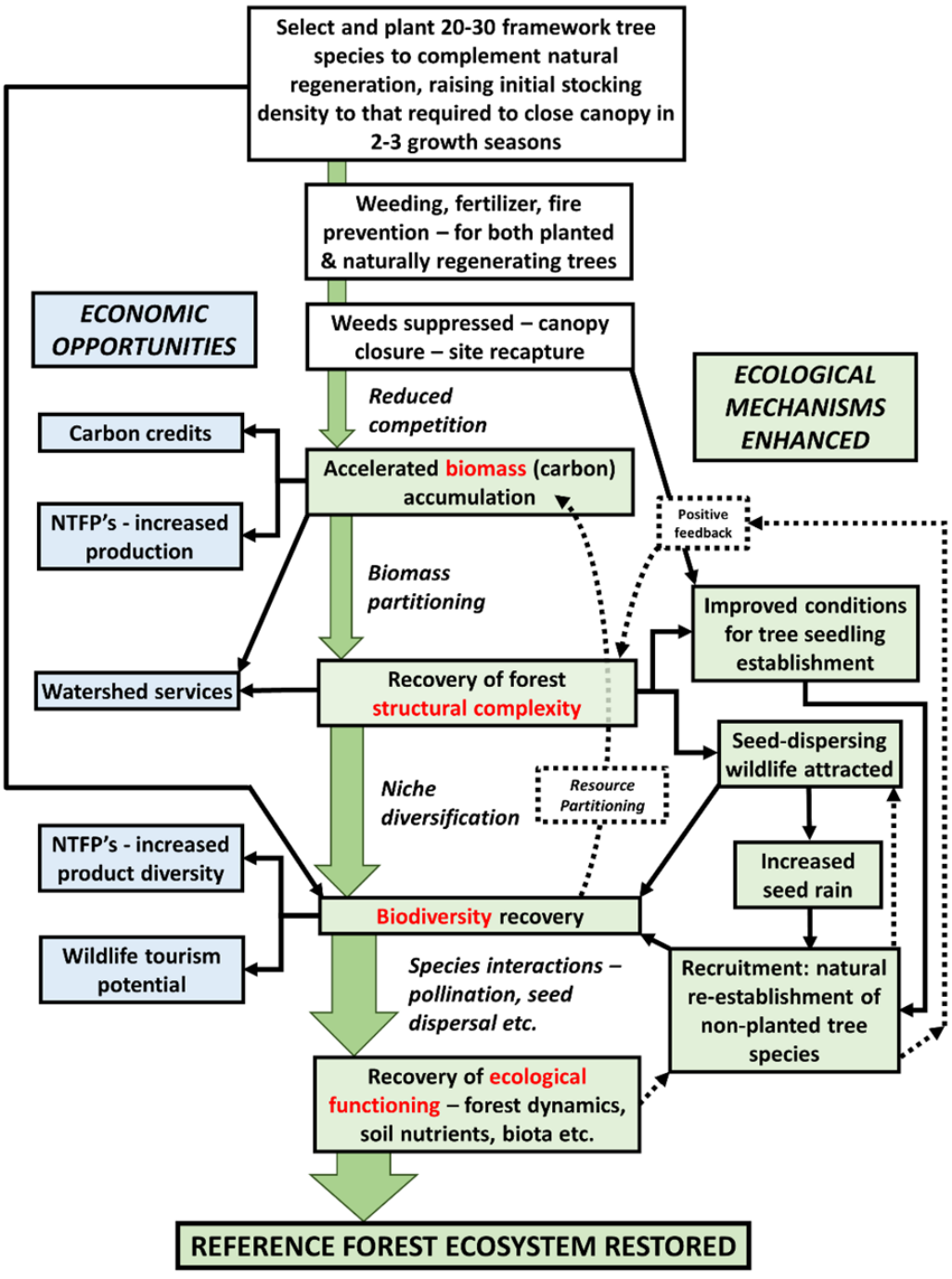


Figure 5.3 How the framework species method works – green arrows indicate progress with restoration objectives; black arrows – origin affects point; dotted arrows – positive feedback loops.

5.4.2 SPECIES SELECTION

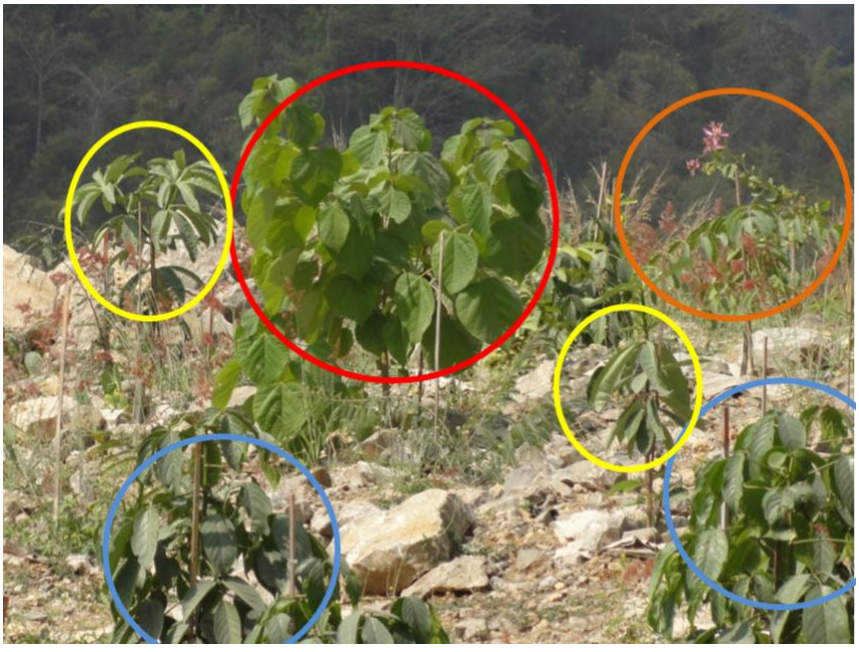
Select species representative of the target forest eco-system of proven high performance on the mine or in highly degraded decid-uous forest ecosystems.

Few field trials have been carried out, to test which native forest tree species might function well as framework tree species on limestone mine sites. Furthermore, existing trials are still young, so it is not yet possible to recommend species for planting with certainty. Appendix lists trees, known to grow in limestone areas of N. Thailand, below 800 m. These tree species are recommended for trialling on limestone quarries. Subsequent data, collection from field trials, will confirm the extent to which they meet the framework species criteria listed in the previous section. Abbreviations in the table in the appendix are as follows: -

LOW/UPP= lowest/highest elevation at which the species has been observed in northern Thailand (m above seas level).
SEED COLL MONTH: Optimum seed collection month which yields maximum %germination

Habitat:	**rocks in**	**deciduous dipterocarp/oak**	**dof**
		pine dipterocarp	**do/pine**
	streams in	**bamboo/deciduous forest**	**bb/df**
		mixed deciduous/evergreen	**mxf**
	ponds in	**evergreen forest**	**egf**
		evergreen with pine	**eg/pine**
	wet areas in	**evergreen with bamboo**	**eg/bb**
		disturbed areas, roadsides	**da**
	cliffs	**secondary growth**	**sg**
		beaches	**be**

Figure 5.4. Some of the more framework tree species identified during trials at SCG's Lampang Limestone Quarry (9 months after planting)



Ficus species and those in the family Leguminosae should be considered first for planting trials, since the former can rapidly open out the substrate through root pressure and facilitate drainage and aeration and the latter can fix nitrogen and rapid improve substrate chemistry, thus ameliorating site conditions and facilitating establishment of other tree species.

Include fig trees and legumes amongst the mix of framework species planted.

Ficus species, known to thrive on limestone substrates, include *F. auriculata* Lour., F. *benjamina L.* var. *benjamina, F. callosa* Willd., *F. capillipes* Gagnep., *F. fistulosa,* Reinw. ex Bl. var. *fistulosa, F. glaberrima* Bl. var. *glaberrima, F. heteropleura* Bl. var. *heteropleura, F. hirta* Vahl. var. *hirta, F. hispida* L. f. var. *hispida, F. microcarpa* L. f. var. *microcarpa forma microcarpa, F. racemosa* L. var. *racemosa, F. rumphii* Bl., *F. semicordata* B.-H. ex J.E. Sm. *var. semicordata, F. variegata* Bl. var. *variegata* and *F. virens* Ait. var. *sublanceolata* (Miq.) Corn.

Suitable legumes include: *Acrocarpus fraxinifolius*, *Albizia lebbeck*, *Bauhinia variegata*, *B. purpurea*, *Cassia fistula*, *Erythrina subumbrans*, *Xylia xylocarpa*. In addition, the five endangered, vulnerable and theratened legume species listed in table 5.1 (*Dalbergia* and *Pterocarpus* species) should be included amongst the framework species planted to prevent their potential extirpation from the site and to contribute towards global tree-conservation initiatives.

5.5 MAINTAIN EXISTING AQUATIC HABITATS AND EXPLORE POTENTIAL TO CREATE NEW ONES

SCG has created various artificial aquatic habitats, notably ponds along the stream that flows through the conservation forest into Kiew Lom Reservoir to the north. These, along with the stream itself and the reservoir margins are essential habitat components, providing drinking water to terrestrial wildlife, as well as habitat for fish, amphibians and waterfowl. Therefore, it is essential that such aquatic habitats do not become silted up or polluted, and that water levels are maintained.

Action points:

Maintain wetlands, both natural and artificial, and consider creating a larger area of open water.

I) monitor water quality at appropriate intervals for pollutants and silt load and take action to reduce siltation and deal with sources of pollution as needed,

II) dredge the ponds, as needed, to reverse siltation and maintain open water of sufficient depth and

III) explore the possibility of creating a larger area of open water as a wildfowl sanctuary.

Table 5.1 – Species most likely to act as framework tree species for restoration of forest ecosystems to a limestone quarry in northern Thailand. Data are from CMU Herbarium Database and FORRU-CMU unpublished research data. Species highlighted in yellow can be recommended on the basis of field results from SCG's mine at Muang Poon. The other species are known to grow well on limestone substrates, but their suitability should be verified by field trials.
Ficus spp. (highlighted in blue) and Legumes (highlighted in green) should receive top priority for field trials.

Species	FAMILY	Low	Upp	Habitat	SEED COLL MONTH
Acrocarpus fraxinifolius **Wight ex Arn.**	**Leguminosae C**	**500**	**1,250**	**bb/df (streams) mxf egf**	**APR**
Albizia lebbeck **(L.) Bth.**	**Leguminosae M**	**60**	**800**	**bb/df mxf eg/bb da sg**	**OCT**
Alstonia scholaris **(L.) R. Br. var. scholaris**	**Apocynaceae**	**60**	**1,200**	**streams in bb/df mxf egf**	**FEB**
Anthocephalus chinensis **(Lmk.) A. Rich.**	**Rubiaceae**	**400**	**1,050**	**mxf**	**OCT**
Aporusa villosa **(Lindl.) Baill.**	**Euphorbiaceae**	**60**	**1,500**	**dof mx/bb mx/pine bb/df do/pine mxf**	**MAY**
Artocarpus lakoocha **Roxb.**	**Moraceae**	**200**	**1,500**	**dof bb/df egf mxf da sg**	**JUN**
Balakata baccata **(Roxb.) Ess.**	**Euphorbiaceae**	**375**	**1,500**	**streams in mxf egf bb/df dof**	**JUL**
Bauhinia purpurea **L.**	**Leguminosae C**	**350**	**950**	**da**	**MAR**
Bauhinia variegata **L.**	**Leguminosae C**	**350**	**1,500**	**da sg in egf bb/df, limestone cliffs mxf**	**APR**
Bischofia javanica **Bl.**	**Euphorbiaceae**	**200**	**1,300**	**bb/df(streams) mxf da eg/pine eg/bb**	**JUL**
Bombax ceiba **L.**	**Bombacaceae**	**60**	**1,450**	**dof mxf da in eg/pine bb/df sg**	**APR**
Bridelia glauca **Bl. var.** ***glauca***	**Euphorbiaceae**	**300**	**1,625**	**mxf egf da dof bb/df eg/pine do/pine**	**MAR**
Canarium subulatum **Guill.**	**Burseraceae**	**60**	**1,300**	**mxf dof bb/df egf da sg**	**SEP**
Cassia fistula **L.**	**Leguminosae C**	**60**	**1,050**	**bb/df dof mxf da sg**	**APR**
Chukrasia tabularis **A. Juss.**	**Meliaceae**	**60**	**1,240**	**bb/df mxf egf**	**MAR**
Croton roxburghii **N. P. Balakr.**	**Euphorbiaceae**	**200**	**950**	**bb/df mxf sg dof**	**APR**
Cycas pectinata **B.H.**	**Cycadaceae**	**60**	**1,750**	**dof eg/pine mxf do/pine da**	**APR**
Erythrina subumbrans **(Hassk.) Merr.**	**Leguminosae P**	**200**	**1,680**	**mxf egf bb/df**	**MAR**

Species	FAMILY	Low	Upp	Habitat	SEED COLL MONTH
Eugenia fruticosa (DC.) Roxb.	Myrtaceae	350	1,515	eg/pine dof bb/df	MAY
Ficus auriculata Lour.	Moraceae	375	1,400	streams in mxf da in dof bb/df egf eg/pine	FEB
Ficus benjamina L. var. *benjamina*	Moraceae	60	1,400		FEB
Ficus callosa Willd.	Moraceae	500	1,100	streams in bb/df mxf egf	APR
Ficus capillipes Gagnep.	Moraceae	475	1,100	bb/df mxf streams	JUN
Ficus fistulosa Reinw. ex Bl. var. *fistulosa*	Moraceae	200	1,400	mxf da in eg/pine bb/df sg egf	JAN
Ficus glaberrima Bl. var. *glaberrima*	Moraceae	450	1,200	mxf egf streams in bb/df rocks	MAY
Ficus heteropleura Bl. var. *heteropleura*	Moraceae	350	1,200	bb/df mxf egf streams rocks	MAR
Ficus hirta Vahl var. *hirta*	Moraceae	60	1,550	mxf egf eg/pine da sg bb/df	JUN
Ficus hispida L. f. var. *hispida*	Moraceae	60	1,525	da sg mxf egf bb/df	APR
Ficus microcarpa L. f. var. *microcarpa* forma *microcarpa*	Moraceae	200	1,100	streams in dof bb/df mxf egf	DEC
Ficus racemosa L. var. *racemosa*	Moraceae	60	650	streams in dof bb/df mxf	JAN
Ficus rumphii Bl.	Moraceae	60	600	bb/df streams da sg	OCT
Ficus sarmentosa B.-H. ex J.E. Sm. var. *nipponica* (Fr. & Sav.) Corn.	Moraceae	550	1,400	egf eg/bb bb/df mxf	AUG
Ficus semicordata B.-H. ex J.E. Sm. var. *semicordata*	Moraceae	200	1,550	da sg in bb/df egf eg/pine	JAN
Ficus variegata Bl. var. *variegata*	Moraceae	300	1,250	streams in mxf egf bb/df	JUN
Ficus virens Ait. var. *sublanceolata* (Miq.) Corn.	Moraceae	525	1,250	rocks in bb/df mxf open egf	MAR
Glochidion kerrii Craib	Euphorbiaceae	550	1,600	egf eg/bb da eg/pine	FEB
Gochnatia decora (Kurz) Cabr.	Compositae	200	1,600	eg/pine often in da sg ls	MAR
Gmelina arborea Roxb.	Verbenaceae	350	1,475	dof bb/df mxf egf eg/pine	APR

Species	FAMILY	Low	Upp	Habitat	SEED COLL MONTH
Holarrhena pubescens (B.-H.) Wall. ex G. Don	Apocynaceae	200	1,050	mxf bb/df mxf dof da sg	FEB
Ilex umbellulata (Wall.) Loesn.	Aquifoliaceae	500	1,500	mxf egf bb/df eg/bb eg/pine	SEP
Lagerstroemia villosa Wall. ex Kurz	Lythraceae	300	1,150	da sg bb/df egf	NOV
Magnolia champaca L. var. champaca	Magnoliaceae	600	1,600	egf mxf	JUN
Mallotus philippensis (Lmk.) M.-A.	Euphorbiaceae	60	1,500	da bb/df mxf sg egf	FEB
Mangifera caloneura Kurz	Anacardiaceae	350	1,025	mxf bb/df egf streams	MAY
Markhamia stipulata (Wall.) Seem. ex K. Sch. var. *kerrii* Sprague	Bignoniaceae	60	1,550	bb/df sg mxf egf eg/pine da	MAR
Millingtonia hortensis L. f.	Bignoniaceae	60	800	bb/df mxf da sg cult cliffs	MAR
Morinda tomentosa Hey. ex Roth	Rubiaceae	60	850	dof bb/df mxf da sg	JUL
Oroxylum indicum (L.) Kurz	Bignoniaceae	60	1,450	bb/df da sg in mxf cult	FEB
Phoebe lanceolata (Nees) Nees	Lauraceae	550	1,600	egf streams in eg/pine da sg mxf	SEP
Spondias lakonensis Pierre	Anacardiaceae	450	850	mxf streams	DEC
Spondias pinnata (L. f.) Kurz	Anacardiaceae	60	1,200	bb/df mxf open egf dof	DEC
Sterculia villosa Roxb.	Sterculiaceae	200	1,600	dof bb/df mxf eg/pine da do/pine	APR
Streblus asper Lour. var. asper	Moraceae	60	900	streams in mxf da sg bb/df	APR
Tectona grandis L. f.	Verbenaceae	60	900	bb/df mxf da sg cult	MAR
Toona ciliata Roemer	Meliaceae	75	100	eg/bb	SEP
Tristaniopsis burmanica (Griff.) P.G. Wilson & T.Waterh.	Euphorbiaceae	600	800	mxf	JUL
Vitex canescens Kurz	Verbenaceae	60	900	bb/df mxf da sg	MAY
Vitex peduncularis Wall. ex Schauer	Verbenaceae	60	1,200	dof bb/df mxf da egf	AUG
Vitex quinata (Lour.) Will.	Verbenaceae	200	1,500	bb/df egf mxf da sg	JAN
Xylia xylocarpa (Roxb.) Taub. var. *kerrii*	Leguminosae M	60	1,000	dof bb/df mxf	MAR

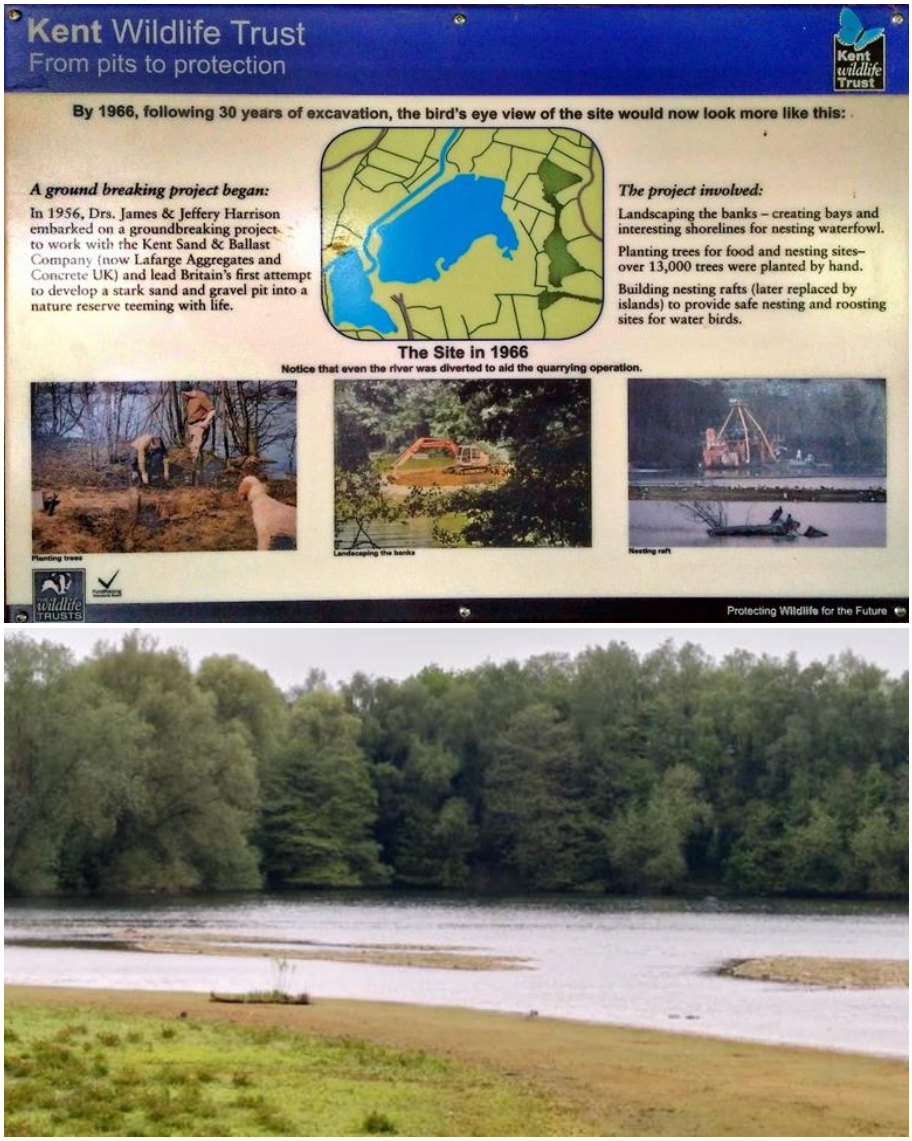


Figure 5.6 – In Kent, UK, a limestone quarry was turned into a wildfowl sanctuary. The quarry was lined and flooded. Islands and shallows created. Water level is controlled by sluices.

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6 SPECIES-FOCUSED MANAGEMENT

6.1 CONTROL INVASIVE EXOTIC SPECIES

Two exotic trees on the mine concession area are potentially invasive: *Delonix regia* and *Leucaena leucocephala,* both of which were mistakenly planted by SCG during former (less well informed) attempts at regreening the site. However, only the latter is a serious threat to habitat restoration and as such, it should be eliminated from the area, particular in and around open restoration sites.

Leucaena leucocephala seriously threatens forest restoration

6.1.1 ELIMINATE *LEUCAENA LEUCOCEPHALA* FROM THE AREA

L. leucocephala (Leguminosae) grows as a shrub or tree from tropical America. It has been spread around the tropics mostly as a fodder plant. It is registered as an invasive weed of concern in 25 countries. It spreads rapidly on mine sites, along roadsides and stream banks and across the draw-down margins of reservoirs. The subspecies *leucocephala* favours limestone and other alkaline soils (Walton, 2003). Being shade intolerant, the species does not penetrate far into closed-canopy forest, but it easily overwhelms tree saplings, planted in open areas for forest restoration purposes. Not only does it outcompete the planted trees for water. Light and nutrients, it is also strongly allelopathic (Boaprem, 2018).

Controlling Leucaena leucocephala is a long-term process involving multiple techniques.

It spreads via seeds, dispersed by both wind and animals. Along roadsides, the seeds are transported by becoming caught in the tyre tread of vehicles. Dense soil seed banks accumulate beneath *L. leucocephala* stands. So, removal of the plants can be rapidly counter-acted by germinating seeds. The main threats to survival of *L. leucocephala* seedlings are shade and competition with grasses and bamboos. Both physical and chemical control measures have been used against this species. Control costs are estimated to be about $1,000 per hectare. Small seedlings are uprooted by hand. Larger plants are cut, close to ground level, and the stump painted with triclopyr 240 g/L + picloram 120 g/L (1 L per 60 L diesel). Covering the stumps in black plastic is also effective at preventing resprouts. Glyphosate has also been used; applied to cut stumps, injected into

stems and as a foliar herbicide on young seedings and saplings. Peng et al., (2019) reported that, injection of 3 ml of glyphosate into the trunk of *L. leucocephala* during the dry season was most effective at inhibiting crown sprouting, but this technique is ineffective when applied in the rainy season. If herbicide usage is not an option, felling adult trees, and covering the stumps in thick black plastic along with cutting out new sprouts as they emerge is the next best option.

Figure 6.1 – Above: in a restoration plot at SCG's Saraburi mine, a rising green tsunami of L. leucocephala is killing planted trees and preventing canopy closure, thus perpetuating the open conditions needed for the species' persistence. Below: in an adjacent plot, bamboos have completely eliminated L. leucocephala, by out-competing it for light, water and nutrients, and by exuding allelochemicals from a dense carpet of leaf litter.

Action points:

i) Implement a comprehensive *L. leucocephala* eradication program, focusing first on the restoration plots and moving outwards to eliminate seed sources:
   a. monitor restoration plots closely for *L. leucocephala* infestation (it usually starts 2-3 years after planting),
   b. remove *L. leucocephala* seedlings on restoration sites by hand at 6-8-week intervals throughout the rainy season, being sure to dig out roots,
   c. cut larger saplings or mature plants; apply herbicide to the stumps or cover them with thick black plastic,
   d. locate seed sources close to the restoration plots; inject with glyphosate or cut and apply herbicide to the stump or cover with black plastic,
   e. lastly remove the mature *L. leucocephala* trees along roads leading to the pits, using the same treatments;

Eradicate L. leucocephala from restoration plots and then remove seed sources further afield.

ii) if the prescribed treatments do not work, then perform experiments to develop more effective eradication treatments, more suited to local conditions and

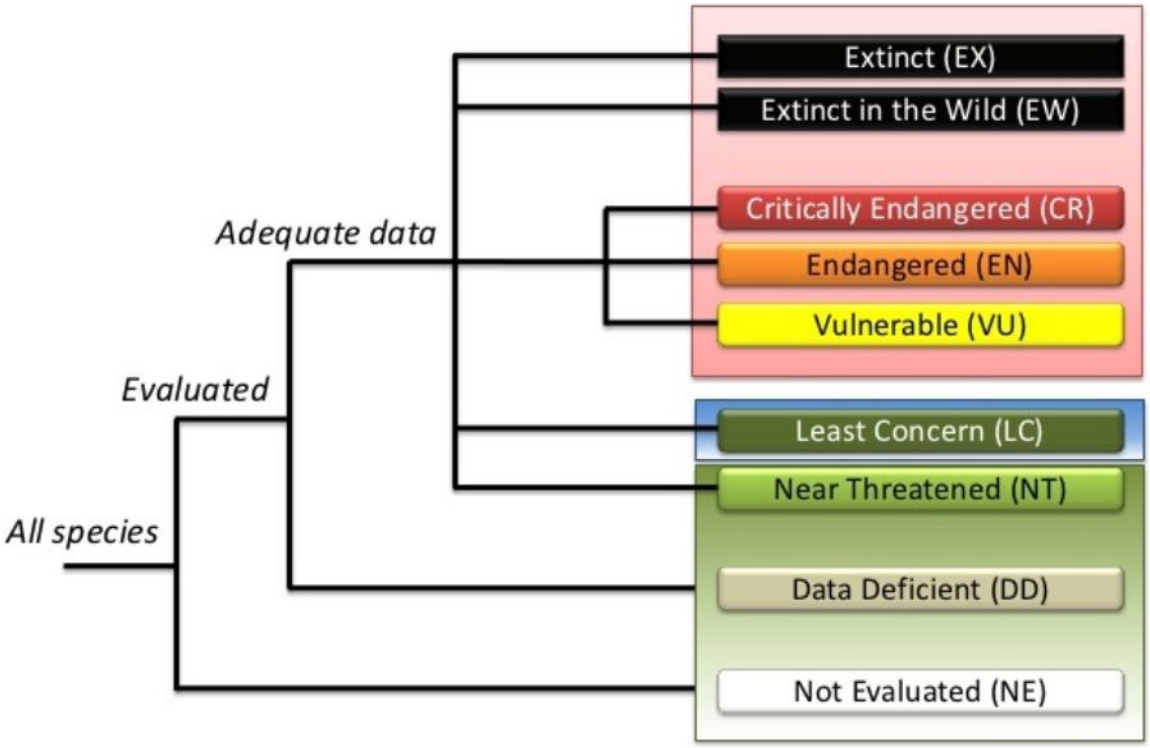
iii) experiment with adding bamboos to the framework tree species planted as a natural way to prevent *L. leucocephala* infestation.

Experiment to test alternative eradication treatments

Figure 6.2 – Left: large Leucaena trees along the SCG Lampang mine roads are a prolific seed source. Right: Leucaena seedlings invading a 2-year-old restoration plot have nearly killed off the planted trees.

6.2 MONITOR SPECIES OF CONCERN

The IUCN classification system for species, according to how close they are to extinction is as follows:



Twenty-three species in the SCG Lampang concession area are of concern and should be prioritized for monitoring, to detect declining populations.

Various species ranked CR, EN, VU and NT have been recorded at the SCG Lampang mine concession area, mostly in the conservation forest and are listed in table 6.1. The rest are of "least concern". Critically endangered species are likely to become extinct imminently, whilst endangered species have extremely low and declining populations. Two bird species, two mammal species, four tree species and 3 reptile species are in these categories. Vulnerable species are those undergoing substantial population decline and are likely to become endangered unless the factors causing the decline are mitigated. Two mammal species, two tree species and one reptile species are in this category. Near threatened species are those close to being classified as endangered or vulnerable, requiring close monitoring. One mammal, 5 tree species and two reptiles at the SCG Lampang mine fall in this category. Monitoring should determine the current status of all these species in the concession area, whether populations are declining and if so, the reason for the decline.

Table 6.1 – Species recorded at the SCG Lampang Limestone Quarry ranked by IUCN as close to extinction (2 birds, 4 mammals, 6 reptiles and 11 trees).

Type	Specific Name	Family	Thai Name	Status
Aves	*Chloropsis cochinchinensis*	Chloropseidae	นกเขียวก้านตองปีกสีฟ้า	EN
Aves	*Pavo muticus*	Phasianidae	นกยูง	EN
Mamalia	*Arctonyx collaris*	Mustelidae	หมูหริ่ง	VU
Mamalia	*Macaca assamensis*	Cercopithecidae	ลิงวอกภูเขา / ลิงไอ้เงี๊ยะ	NT
Mamalia	*Macaca nemestrina*	Cercopithecidae	ลิงกัง	VU
Mamalia	*Manis javanica*	Manidae	ลิ่นชวา	CR
Mamalia	*Nycticebus bengalensis*	Lorisidae	ลิงลมเหนือ	EN
Plant - tree	*Dialium cochinchinense*	Fabaceae	หยี	NT
Plant - tree	*Aegle marmelos*	Rutaceae	มะตูม	NT
Plant - tree	*Afzelia xylocarpa*	Fabaceae	มะค่าโมง	EN
Plant - tree	*Aglaia grandis*	Meliaceae	ลางสาดป่า	NT
Plant - tree	*Anogeissus acuminata*	Combretaceae	ตะเคียนหนู	NT
Plant - tree	*Cryptocarya pallens*	Lauraceae	หมากขี้อ้าย	VU
Plant - tree	*Dalbergia cochinchinensis*	Fabaceae	พะยูง	VU
Plant - tree	*Dalbergia cultrata*	Fabaceae	กระพี้เขาควาย	NT
Plant - tree	*Dalbergia oliveri*	Fabaceae	ชิงชัน	EN
Plant - tree	*Pterocarpus indicus*	Fabaceae	ประดู่บ้าน	EN
Plant - tree	*Pterocarpus macrocarpus*	Fabaceae	ประดู่ป่า	EN
Reptilia	*Indotestudo elongata*	Testudinidae	เต่าเหลือง	CR
Reptilia	*Malayemys subtrijuga*	Geoemydidae	เต่านา	NT
Reptilia	*Manouria impressa*	Testudinidae	เต่าควะ	EN
Reptilia	*Ophiophagus hannah*	Elapidae	งูจงอาง	VU
Reptilia	*Varanus bengalensis*	Varanidae	ตะกวด	NT
Reptilia	*Varanus flavescens*	Varanidae	แลนดอน	EN

Regular monitoring of these species is essential, to detect declining populations and take appropriate conservation action to prevent species losses and overall biodiversity decline.

Action points:

i) **trees**: detect the locations of the tree species listed in table 6.1 during regular assessments of overall plant diversity (Section 8); in addition, use drones to search for them when their crowns are most distinctive (usually when flowering) (Rai and Elliott, 2021); record the GPS locations of the trees and check their status annually, as most of them are highly valued timber species, targeted by timber poachers,

ii) **mammals**: continue with camera trapping in the conservation and buffer zone forest to detect the continued presence of the mammal species listed in table 6.1; for estimations of population status and trajectories, the methods reviewed by Palencia et al. (2021) are recommended,

iii) **birds**: the two endangered bird species should be easily detected during the annual bird surveys recommended for overall biodiversity monitoring on the site (see Section 8),

Select monitoring protocols suitable for each animal class and for rare tree species.

iv) **reptiles**: some reptiles may be confirmed by camera trapping (SCG already runs a camera trapping program onsite), but camera traps cover a very small area; consequently, visual encounter surveys (VES) are likely to yield better data, particularly for the rare species, listed in table 6.1; the techniques described by Doan, 2003 are recommended, to perform annual VES assessments and

v) engage SCG staff and visitors in incidental monitoring, by enabling them to identify the animal species, listed in table 6.1, and by encouraging them to report any sightings they have ("citizens' science") via a phone app.

Involve SCG staff in citizens' science approach.

6.3 CONSERVATION ACTIONS TARGETING SPECIES OF CONCERN

Conservation management options will depend on the results of the monitoring.

Until the monitoring, recommended in the previous section, has determined the status and population trajectories of the species listed in table 6.1 and the causes of any population decline detected are identified, it is not possible to prescribe species-specific management actions, since conservation measures vary according to species and according to the type of factors causing population decline. However, some generalized species-level conservation actions can be recommended here.

6.3.1 PLANTS

Action points:

i) **trees**: having located seed trees of the species listed in table 6.1 during monitoring (Section 6.2), perform phenology studies, to determine optimum seed-collection time, and collect seeds from as many individual trees of each species as possible, to maintain genetic diversity; grow planting stock in the on-site nursery,

ii) include saplings of the species listed in Table 6.1 amongst the framework species planted in restoration plots on the pits; most are legumes that will improve soil nutrient levels

iii) several are extremely high-value "rosewood" timber species (30,000-40,000 US$/ton)—which may account for their decline—including *Dalbergia cochinchinensis* and *D. oliveri* and both *Pterocarpus* species; therefore, donate

excess seedlings of these species to local farmers to uplift and diversify local livelihoods, raise community support for maintaining the conservation forest and increase populations of these rare and declining species,

iv) **orchids**: many orchid species, typical of the bamboo-deciduous forest, have been extirpated despite security measures; therefore, instigate an orchid propagation and re-introduction program, in collaboration with QSBG or CMU to re-establish this highly speciose and ecologically functional plant group. Species recommended for the habitat type and altitude range of the conservation forest in the concession area are listed in Table 6.2.

Table 6.2 – Orchid species recommended for propagation and re-introduction

Species	Altitude Range	Flowering
Aphyllorchis montana Rchb. f.	500-1200	jl-sp
Aerides falcata Lindl.	350-350	my-jn
Brachcorythis helferi (Rchb. f.) Summ.	550-1000	jl-nv
Brachycorythis henryi (Schltr.) Summ.	500-700	jl-ag
Cleisostoma filiforme (Lindl.) Garay	400-1200	my-jn
Cymbidium flexuosum	350-350	my-jn
Dendrobium gratiosissimum Rchb. f.	425-425	ap-my
Dendrobium moschatum (B.-H.) Sw.	550-650	my-jn
Dendrobium venustum Teijsm. & Binn.	425-625	ag-sp
Geodorum attenuatum Griff.	500-950	my-jl
Geodorum citrinum Jacks.	500-600	jn-jl
Geodorum siamense Rol. ex Dow.	425-625	ap-jn
Goodyera procera (Ker-Gawl.) Hk.	575-1050	mr-ap
Habenaria amplexicaule Rol. ex Dow.	450-700	oc-dc
Habenaria furcifera Lindl.	450-650	sp-oc
Habenaria lucida Wall. ex Lindl.	350-700	ag-sp
Habenaria malintana (Blanco) Merr.	450-1300	oc-dc
Habenaria medioflexa Turr.	375-375	nv
Liparis sutepensis Rol. ex Dow.	450-700	jn-ag
Nervilia aragoana Gaud.	375-1250	ap-my
Nervilia calcicola Kerr	625-625	my
Nervilia plicata (Andr.) Schltr.	450-950	ap-my
Peristylus constrictus (Lindl.) Lindl.	500-1525	jn-jl
Phalaenopsis cornu-cervi (Breda) Bl. & Rchb. f.	500-500	ap-my
Pholidota imbricata Hk.	725-725	jl-ag
Tainia angustifolia (Lindl.) Bth. & Hk. f.	450-1075	sp-dc
Tropidia curculigoides Lindl.	450-850	jl-sp

6.3.2 ANIMALS

Action points:

i) continue to implement security measures to prevent hunting,
ii) when the monitoring measures describes above detects declines in animal species of concern, consider supplementary feeding programs, particularly during times of seasonal scarcity (dry season),
iii) likewise, consider habitat manipulation to improve breeding requirements *in situ*, such as nesting zones etc. and
iv) if populations continue to decline, despite implementing the above measures, consider establishing a captive breeding facility, particularly for the endangered and critically endangered reptiles and
v) work with the DNP to re-introduce species from the captive breeding facility into Tum Pah Thai National Park, where their security is assured.

Captive breeding is the last resort, when other conservation measures fail.

6.4 STUDY THE EFFECTS OF DUST AND NOISE ON FOREST ECOSYSTEMS AND WILDLIFE

The effects of noise on wildlife and dust on vegetation are not well known.

Although current dust and noise levels on the mine are within safety standards for humans, set by the National Environment Board (Section 3), their effects on wildlife (both plants and animals) require further investigation, particularly in the tropics (Blickley and Patricelli, 2010). Current noise standards are designed to protect human welfare. They use human criteria of disturbance, generated primarily in areas where humans are impacted. They may not be effective, however, in reducing the impacts of noise on sensitive wildlife species (Blickley and Patricelli, 2010).

Dust from cement plants, deposited on vegetation, has long been known to be responsible for leaf injury, due to the toxicity of alkaline solutions formed in the presence of moisture. Fine particles of cement-kiln dusts interfere with CO_2 exchange and cause considerable leaf injury. This is likely to reduce primary productivity of the forest ecosystems on the mine, reduce biomass and carbon accumulation

and consequently slow recovery of forest structural diversity, which is vital for the recovery of biodiversity (Darley, 1966)

Action points:

i) instigate a study to determine the effects of dust and mitigation measures on the primary production and biomass accumulation of vegetation, comparing roadside with forest-interior vegetation,
ii) instigate a study on the effects of noise on bird behaviour, particularly nesting and
iii) review and, if necessary, modify dust- and noise-mitigation measures on the mine, if these studies show a deleterious effect on plants and wildlife, particularly on the species of concern listed in table 6.1

Mitigation measures should be modified, if necessary, based on measured effects on vegetation and wildlife.

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7 BIODIVERSITY OFFSET

7.1 WHAT IS BIODIVERSITY OFFSETTING?

Biodiversity offsetting compensates for ecosystem destruction or degradation, resulting from land use change during development projects. It involves restoring biodiversity off-site to counterbalance biodiversity loss at the development site, with the goal of achieving "no net loss" and preferably "a net gain" in biodiversity with respect to species composition, habitat structure and ecosystem functioning, as well as people's use of biodiversity and its cultural value" (BBOP, 2009). It is the final option in the mitigation hierarchy (Fig. 7.1).

Biodiversity offset restores biodiversity to one site to compensate for biodiversity loss caused by development of another.

Development project planners should:

i) first seek to avoid damaging any biodiversity (Section 5.3),
ii) then seek to minimize any such damage (Section 6.4),
iii) then consider how to restore sites (Section 5.4) or species populations (Section 6.3) damaged by the project and finally
iv) if adverse biodiversity impacts still remain—compensate through specific actions comprising a biodiversity offset (PROFOR, 2016).

Biodiversity offsets are conservation actions intended to compensate for residual, unavoidable impacts on biodiversity.

An increasing number of mining projects are implementing biodiversity offsets, to compensate for adverse impacts on forest habitats and species and as part of their overall approach to avoid biodiversity losses and thus protect their licenses to operate (ICMM, 2005). This reflects the link of corporate strategies between maintaining healthy ecosystems and sustainable development targets. The type of biodiversity offset applicable to the SCG Lampang Limestone Quarry is Restoration offsets, which involve "restoring, enhancing or establishing biodiversity values in degraded habitats outside the area that is managed by the company". Measures usually entail habitat restoration to foster biodiversity recovery.

Offsets are becoming an accepted component of biodiversity management plans in the mining industry.

Several principles have been developed, to help govern the planning and implementation of biodiversity offsets (BBOP 2009a):

i) Offsets should follow/adhere to the mitigation hierarchy.
ii) There are limits to what can be offset.
iii) Offsets should support landscape-level conservation.
iv) Offsets must provide additional conservation outcomes.
v) Stakeholder input is critical in an offset design.
vi) Offsets should have long-term benefits.
vii) Offset design and implementation must be equitable to all stakeholders

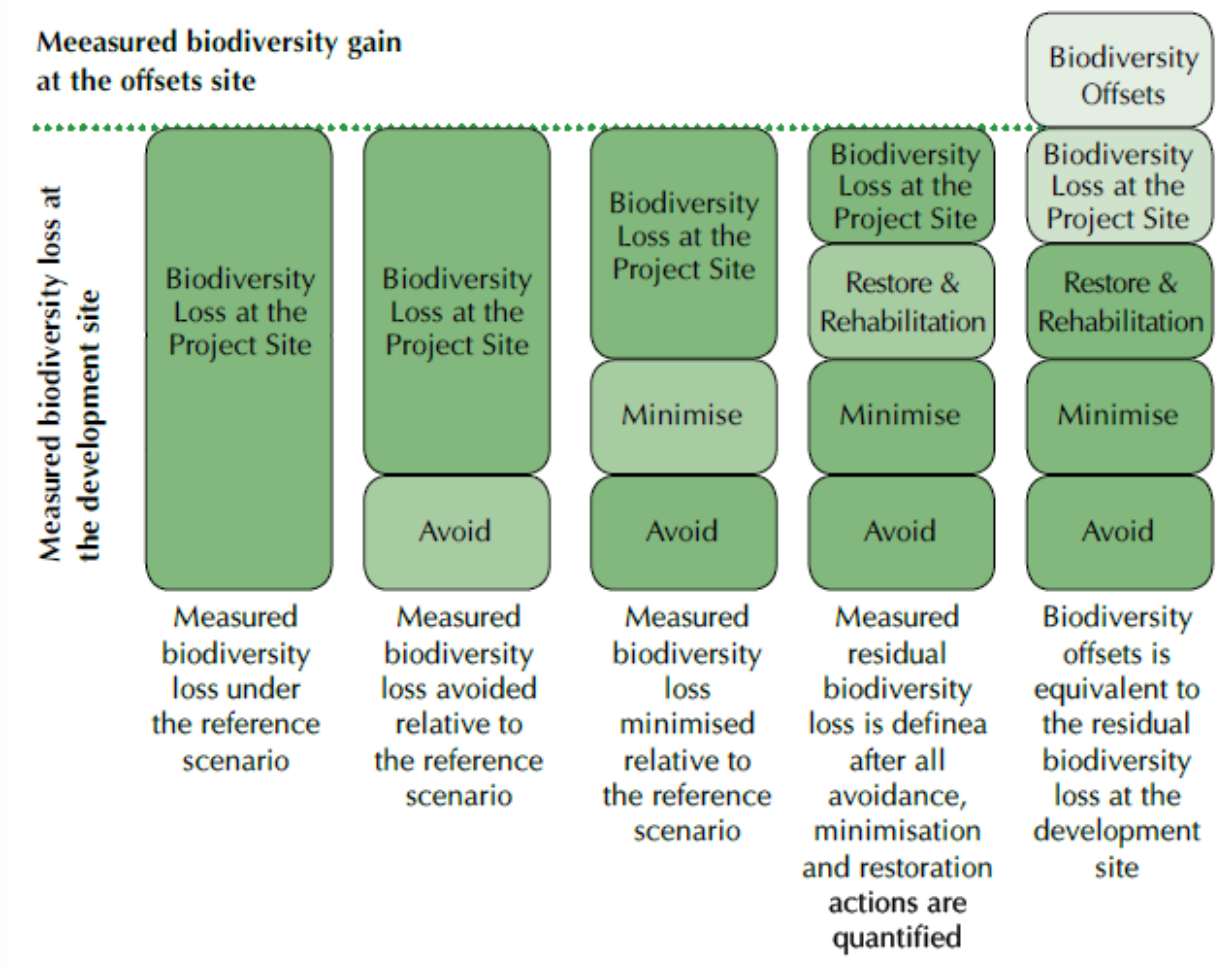

Figure 7.01 Biodiversity offset positions within mitigation hierarchy

7.2 HOW MUCH BIODIVERSITY OFFSET IS REQUIRED?

Biodiversity increases as habitat area increases by the power function:

$$S=CA^z$$

Well-established ecological theories link biodiversity loss with habitat loss.

… where S is the expected number of species in A, a certain area (Wilson, 1992). C and z are empirically derived constants. C relates to the total number of species in the entire area, whereas z relates to the rate of increase/decline in species with increasing/declining area.

To derive values of C and z, specific for bamboo-deciduous forest at the SCG Lampang Limestone Quarry, FORRU-CMU performed field surveys to construct species-area curves for tree species, from a set of increasing numbers of circular sample plots (10 m in diameter). Coleman's equation was used to smooth the curve, calculating the mean numbers of tree species in any fraction of the total sample plots from field data thus:

$$s(a) = S - \sum_{i=1}^{S} (1 - a)^{n(i)}$$

Field data were used to derive the constants needed to establish the species-area relationship specific for bamboo-deciduous forest at SCG Lampang.

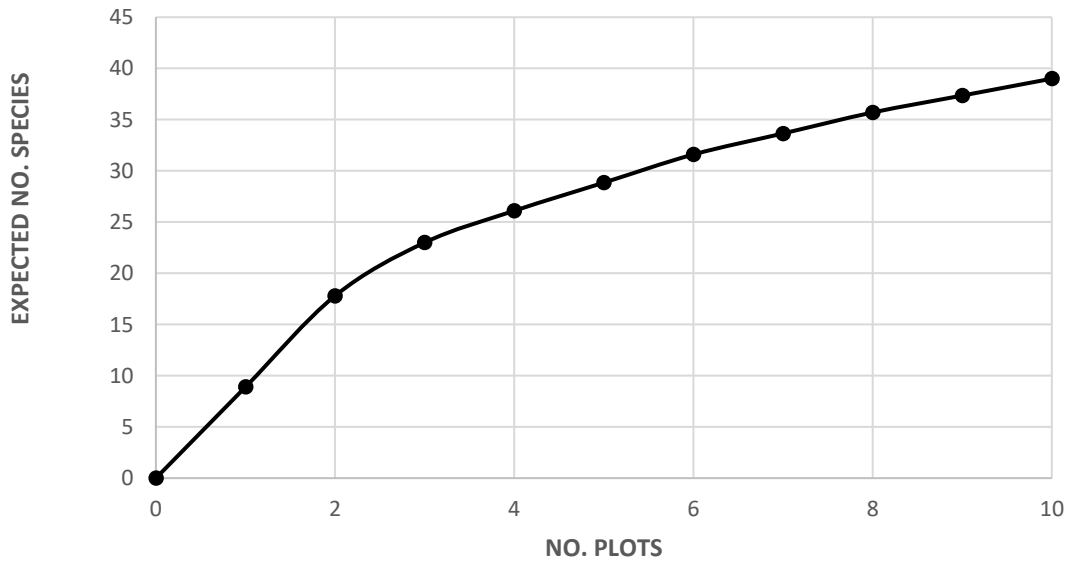

Figure 7.2 - Species-area curve for trees in bamboo-deciduous forest, constructed using Coleman's equation, from field survey data for trees in the conservation forest at SCG Lampang.

From the curve, presented in Figure 7.2, the values of C and z were calculated at 12.3 and 0.51 respectively, using curve-fitting software (CurveExpert Basic 2.2.3) (Fig. 7.3).

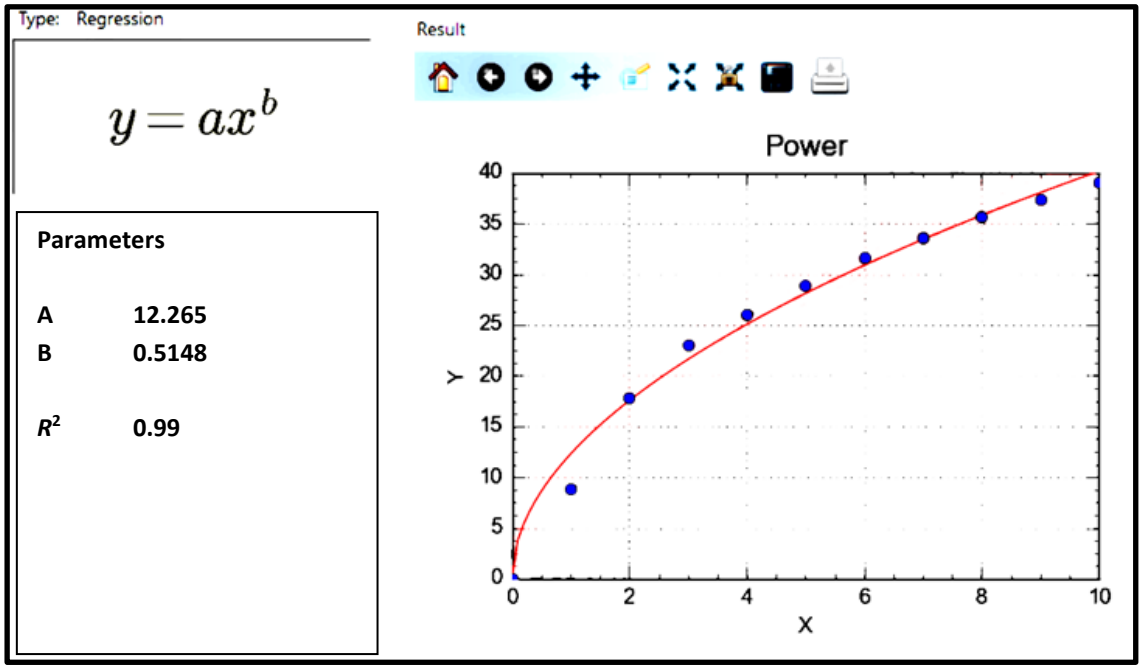

Figure 7.3 - Empirical derivation of C and z from curve fitting field data using CurveExpert Basic 2.2.3 (indicated as "a" and "b" respectively in the model output above).

Trees can be used as a proxy for overall biodiversity.

The z value (0.51) is high, compared with tropical forest values, which are usually in the range on 0.15 to 0.36 (Wilson, 1992). Since trees provide most of the structural diversity, as habitat, needed to support overall biodiversity, they provide an excellent proxy for overall biodiversity and can therefore provide reliable values of C and z. Consequently, using values for C and z, derived from tree species-area curves, it is possible to estimate the expected decline in biodiversity that will result from forest clearance in the mine concession area.

Since SCG could not provide information on the exact area that would remain impacted by infrastructure post mine closure, we calculated the area of forest impacted, using GIS software on maps provided by SCG, based on three scenarios of infrastructure removal (Fig. 7.4).

i) Scenario 1 – least infrastructure removal – most buildings will be repurposed and remain on site and road access to them maintained;
ii) Scenario 2 – medium infrastructure removal – all buildings removed (except the nature centre) and restored to forest, but no roads removed and
iii) Scenario 3 – complete infrastructure removal – all buildings demolished. removed and restored to forest – all roads closed and restored to forest

Three scenarios are necessary to compensate for lack of data provided on levels of infrastructure removal.

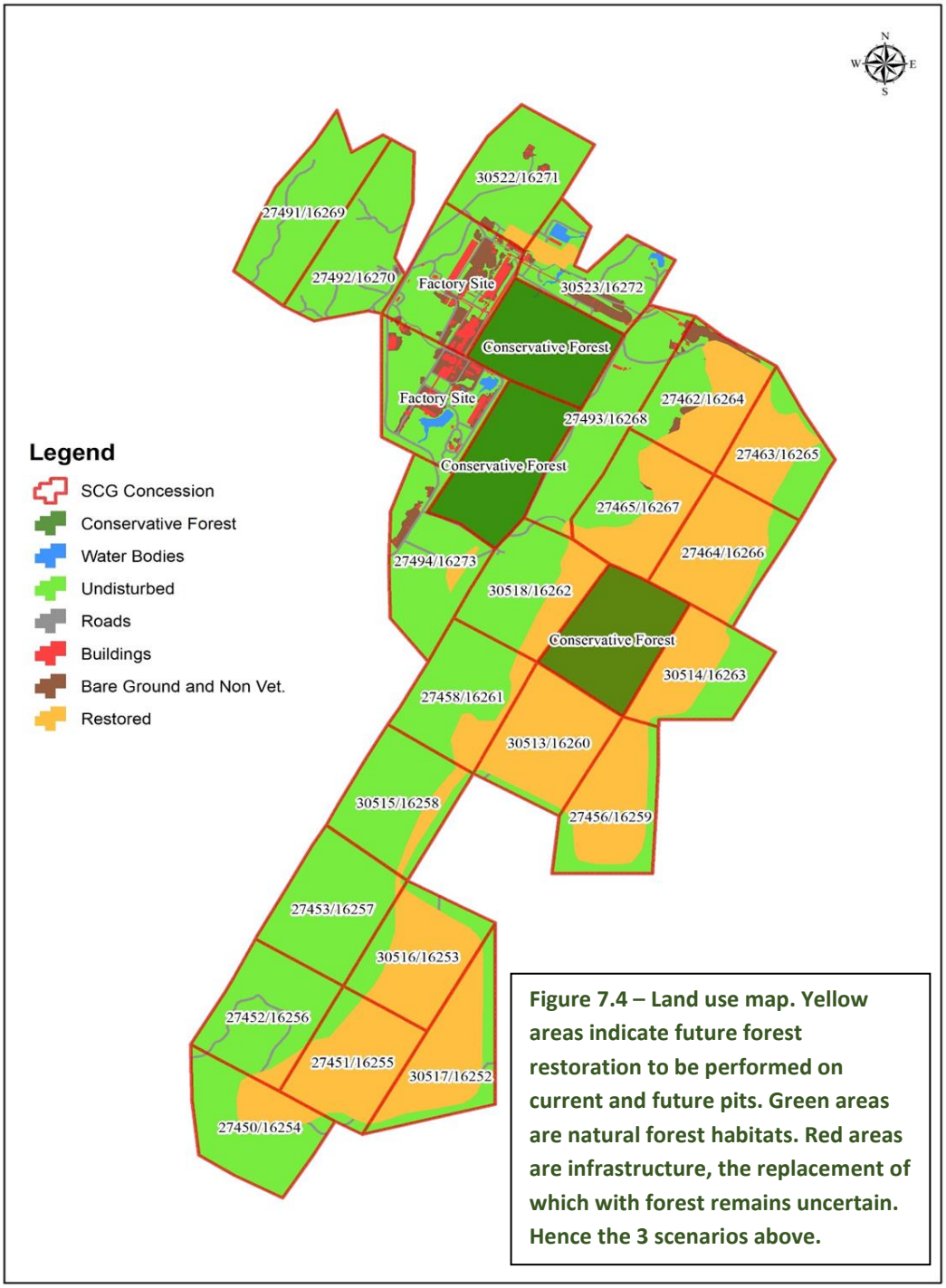

Figure 7.4 – Land use map. Yellow areas indicate future forest restoration to be performed on current and future pits. Green areas are natural forest habitats. Red areas are infrastructure, the replacement of which with forest remains uncertain. Hence the 3 scenarios above.

Please note that the total area indicated in Table 7.1 is larger than the mine concession area indicated in Table 1.1, since it includes conservation forest.

Table 7.1 – Land use areas following mine closure under 3 scenarios of infrastructure removal

		LEVEL OF INFRASTRUCTURE REMOVAL		
		SCENARIO 1 - LEAST	SCENARIO 2 - MEDIUM	SCENARIO 3 - MOST
		AREA REMAINING (SQ KM) POST MINE CLOSER		
FOREST	RESTORED	3.924	4.326	4.569
	UNDISTURBED	6.595	6.595	6.595
	CONSERVATION FOREST	1.419	1.419	1.419
BUILT UP	ROADS	0.305	0.305	0.062
	BUILDINGS	0.142	0.0002	0.0002
OTHER	BARE GROUND	0.26	0	0
	NON-FOREST VEGETATION			
	WATER BODIES	0.041	0.041	0.041
	TOTAL	**12.686**	**12.686**	**12.686**

About 20% of biodiversity on the mine concession area may be lost unless mitigation measures are implemented.

Under all scenarios initial forest loss amounts to 4.6 km^2, which is 36.5 % of the estimated forest habitat present before mining (Figure 7.5). Using the C and z values calculated above, estimated biodiversity loss is therefore about 20%.

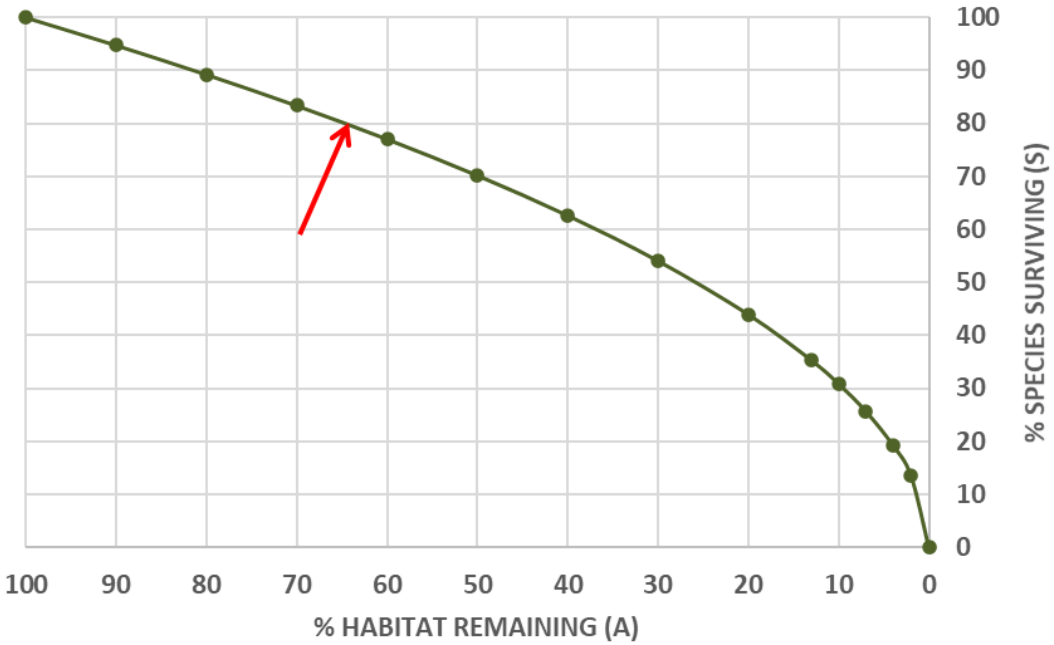

Figure 7.5 – Using the C and z parameter values calculated above, this graph indicates that a 36% reduction in forest area caused by opening the pits and infrastructure development will result in a 20% decline in biodiversity (red arrow).

This is because as habitat area declines, species with small populations fall below the minimum viable population. Inbreeding increases, as close relatives mate with one another. This reduces fecundity and increases risk of vulnerability to diseases. Genetic recovery by outbreeding with nearby populations becomes less likely to occur as habitat connectivity declines, and remaining habitat becomes fragmented. Furthermore, small populations become highly vulnerable to habitat disturbance, as even minor habitat perturbations (e.g., localized fire etc.) impact a significant percentage of the remaining small population. Consequently, as habitat area and quality decline, so the species richness of an area declines to a new lower equilibrium, supportable by the smaller area of remaining habitat (Primack, 2006). The pattern of decline is effectively the reverse of the species-area curves (which address increasing species found with increasing area inspected). So, the C and z values, calculated above, can be used to estimate the likely percentage reduction in species.

Inbreeding and vulnerability to habitat perturbations extirpates species with small populations in small isolated habitat patches.

To some extent this expected decline in biodiversity (known as faunal collapse or relaxation) can be counteracted by closely monitoring species with small populations and taking steps to increase their fecundity and to reduce death rates, as soon as population decline is detected—this approach is dealt with in Section 6.2 & 6.3. In effect, this allows unnaturally high species richness to be maintained even in small habitat patches. However, it requires constant monitoring and adaptive management, which are expensive to maintain in perpetuity, and so, it is ultimately unsustainable. Consequently, increasing habitat area, to levels that will support former biodiversity levels, is more cost effective in the long run.

Faunal collapse is an inevitable result of habitat area reduction.

Species management can help but it is not a long-term solution.

Using the framework species method, to restore forest to the pits and infrastructure sites as they are gradually decommissioned, will also help to mitigate the predicted 20% biodiversity loss. The total area to be restored increases with increasing infrastructure removal (from 3.9 km^2, with no infrastructure removal, to 4.6 km^2, if all buildings and roads are removed). However, despite restoration efforts on the mine, there will remain a net loss in forest of from 0.062 to 0.707 km^2 (Table 7.1)).

Forest restoration solely on the mine on the mine is not

A further consideration is that restored forest usually supports lower biodiversity than that of the former undisturbed forest it seeks to replace, particularly in the first 10 years or so after tree planting.

Biodiversity offset via habitat restoration exchanges *certain* losses for *uncertain* gains. The compensation is realized only after a long-time delay (up to many decades or even centuries in the case of forests), and may only partially be achieved (Suding, 2011). Therefore, a greater area of forest than that destroyed must be restored to compensate for these effects. In the case of the SCG Lampang Mine, this will involve restoring additional forest on degraded areas outside of the immediate mine concession area, to achieve the goal of no net biodiversity loss. The extent to which additional forest off-mine must be restored is determined by the "offset multiplier", defined as the ratio A1:A0 where A1 is the area to be offset and A0 is the area damaged, when no net loss is the goal (Moilanen et al. 2009). Laitila et al. (2014) analytically derived minimum multipliers for offsetting, conditional on time discounting, linear additionality and permanence of gains and provided a spreadsheet for calculating offset multipliers. Using this spreadsheet, assuming 20 years for recovery of 75% biodiversity on restoration plots, and a time discount rate of 5% results in a multiplier of x3.5.

Offset multipliers estimate the amount of additional off-mine restoration necessary to achieve zero net biodiversity loss in the long run.

Table 7.2 – Biodiversity offset by forest restoration required off site to achieve zero net loss using a multiplier of 3.5 derived from Laitila et al. (2014).

	Scenario 1	Scenario 2	Scenario 3
INFRASTRUCTURE			
Area Impacted	0.707	0.707	0.707
Forest Restoration Required for Biodiversity Offset	2.4745	2.4745	2.4745
On-site restoration	0	0.4018	0.6448
Offsite Restoration Required - infrastructure	**2.475**	**2.073**	**1.830**
PITS			
Area Impacted	3.924	3.924	3.924
Forest Restoration Required for Biodiversity Offset	13.734	13.734	13.734
On-site restoration	3.924	3.924	3.924
Offsite Restoration Required - Pits	**9.810**	**9.810**	**9.810**
Total Offset Required – off site	**12.285**	**11.883**	**11.640**

Table 7.2 shows that the area of forest restoration off-site, needed to assure zero net loss of biodiversity (in addition to on-site restoration (Section 5)) ranges from 11.6 to 12.3 km^2, depending on extent of infrastructure removal (and hence the area restored on site). Using

current restoration costs (1,905-4,520 USD/ha, depending on amount of pre-existing natural regeneration on restoration sites and assuming establishment costs are not borrowed (i.e., zero interest payments) (Jantawong et al., 2022)), the cost of biodiversity offset will therefore vary from 2.2-5.5 million USD (72.6-181.5 million THB), depending both on the extent of infrastructure removal from the mine and on the amount of natural regeneration on potential restoration sites; restoration costs decline with increasing density of pre-existing natural regeneration.

7.3 WHERE SHOULD BIODIVERSITY OFFSET BE PERFORMED?

Tham Pha Thai National Park, adjacent to SCG Lampang limestone Quarry provides a highly suitable area for the biodiversity offset component of this biodiversity management plan, since it supports the same forest types as the buffer zone and conservation forests of the quarry, and it contains many large degraded areas in need of restoration. The park is administered by Protected Areas Regional 13 (Lampang), Department of National Parks, Wildlife and Plant Conservation. It is located in Mueang, Chae Hom, Mae Mo, and (mostly) Ngao districts, 65 km from the Lampang town. The park covers 1,253 km^2 of mostly mountainous terrain, with Doi Mae Khwan being the highest peak at 1,253 metres above mean sea level. The park is the sources of the Wang and Ngao rivers.

Tham Pha Thai National Park is an ideal location for biodiversity offset, with potential to provide multiple benefits to various stakeholders.

SCG Lampang has already carried out some forest restoration work in the area and maintains a good relationship with the park authority. Such work has the potential to provide multiple benefits to various stakeholders, in addition to biodiversity conservation, e.g., watershed services (irrigation water for crops downstream, reduced landslides, soil erosion, floods and siltation of watercourses), forest products, ecotourism potential, improved local livelihoods and improved relationship between SCG Lampang and local stakeholders. It is also in line with government conservation goals.

SCG already has a connection with the park.

Forest types match those of conservation forest in the concession area.

Various forest types grow in the park. Along with the bamboo-deciduous forest (which is also typical of the SCG mine concession area), there is mixed deciduous forest, deciduous dipterocarp forest and dry evergreen forest. Forest trees include several species of concern (Table 6.1). *Dalbergia oliveri* (Ching Chan), *Pterocarpus macrocarpus* (Pradoo) and *Afzelia xylocarpa* (Maka Mong) are all listed as "endangered" by the IUCN. The highly valued timber tree *Xylia xylocarpa* (redwood) is common, along with other typical species: *Lithocarpus cantleyanus*, *Lannea coromandelica* (Oay Chang), *Mitragyna diversifolia* (Toom Gwow), *Hymenodictyon excelsum* (U-lok), *Combretum quadrangulare* (Sa-gae) and many bamboo species etc. Rare wild cattle Guar has been sighted in the park, along with several macaque species and many bird and reptile species. A comprehensive biodiversity survey of the park has yet to be performed. Teak plantations cover much of the western part of the park whilst agricultural field have been established in the east, where encroachment is common.

Previous attempts to control encroachment have created offset opportunities.

In 2016, the forest reclamation policy concentrated on clearing rubber plantations out of the national park, mostly in Ngao district. In Ban Pong Sub-district, degradation occurred as a result of a former Teak concession. These events have resulted in several degraded areas, potentially available for biodiversity offsetting. Some sites have already been planted with native forest tree species through collaboration between the park authority, academic institutions and the private sector including SCG.

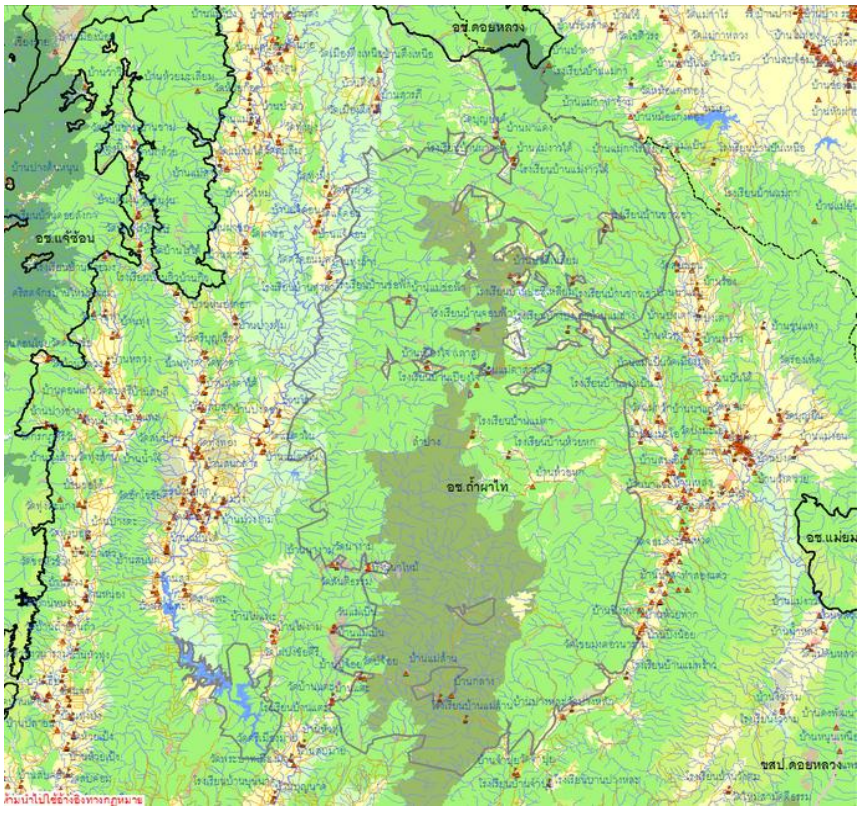

Figure 7.6 - Location and surroundings of Tham Pah Thai National Park

In 2017 and 2018, FORRU-CMU performed framework species trials on two sites within the park. These trials resulted in ranking of species by their field performance, revealing species recommended for habitat creation and biodiversity recovery. Mean species performance index (SPI) was calculated by multiplying survival rate by relative growth rate, and expressing the result as a percentage of the value of the top-performing species. In the 2017 trial *Erythrina subumbrans* was the top performing species (Fig. 7.7). SPI values >50% of that *E. subumbrans* were attained by *Sapindus rarak*, *Bischofia javanica*, *Spondias pinnata*, *Tectona grandis*, *Balakata baccata*, *Syzygium cumini* and *Gmelina arborea*. Mortality rates of planted seedlings was exceptionally high at this site largely due to fire, indicating the essential need for investment in fire prevention measures along with weeding and fertilizer application.

Figure 7.7 - The top perf-orming tree species in the 2017 restoration trials in Tham Pah Thai National Park: *Erythrina subum-brans*, at the ned of the second rainy season after planting.

In the 2018 trial (Figure 7.08) growth rates were not measured, but survival of planted trees averaged 74% at the end of the second rainy season. Species with survival rates exceeding 70% were: *Albizia lebbeck, Artocarpus lakoocha, Cassia fistula, Ficus hispida, Glochidion rubrum, Lagerstroemia macrocarpa, Samanea saman, Spondias pinnata, Bischofia javanica, Protium serratum. Pterocarpus macrocarpus, Afzelia xylocarpa, Phyllanthus emblica* and *Erythrina subumbrans.* The main cause of mortality was slashing, during careless weeding operations, followed by cattle browsing. This indicates the need to carefully supervise weeding and to exclude cattle from restoration sites with fencing.

Figure 7.08 – Villagers pose in front of 2-year-old trees planted in 2018 in Tham Pah Thai National Park

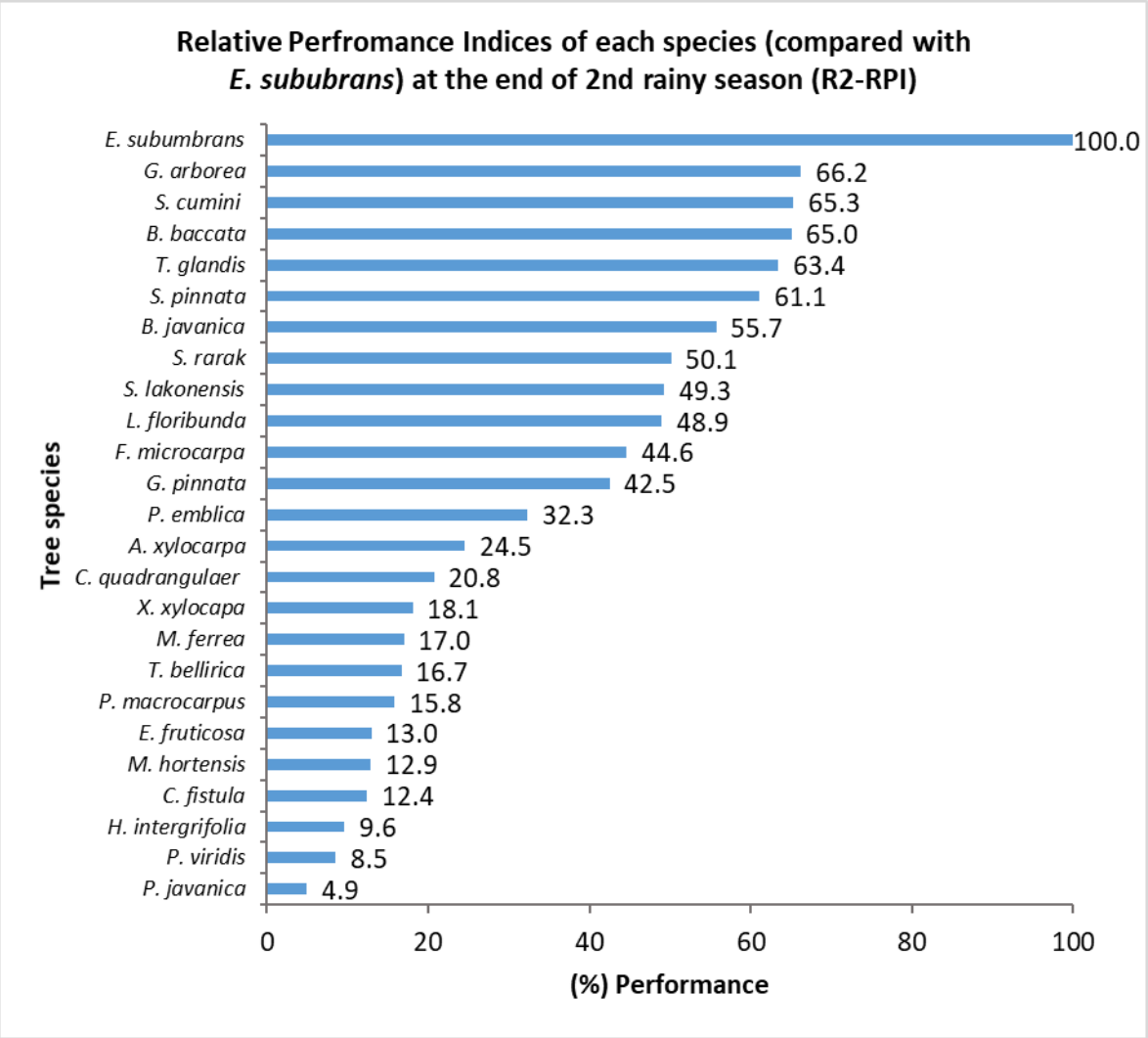

Figure 7.9 - Species ranked in relative SPI in the 2017 restoration trials, in Tham Pah Thai National Park, at the end of the second rainy season after planting. Recommended species at the top

Figure 7.10 Villagers and DNP staff planting trees in Tham Pah Thai Nationa

Action points:

i) restore 11.6 – 12.3 km^2 of bamboo-deciduous forest on former teak-plantation sites in Than Pah Thai National Park, using the conservation forest on the mine as a reference forest type

ii) ensure that the restoration project supports local and national conservation policies and targets (e.g., Thailand's contribution to the Convention on biodiversity);

iii) perform stakeholder consultations, to facilitate inclusive decision-making and to help define multiple benefits from offsets (e.g., synergies in the restoration of biodiversity and ecosystem services, accounting for accessibility and other socio-economic outcomes);

iv) perform offsets actions to maximize habitat connectivity, both within the national park and between the park and buffer zone or conservation forest in the mine concession area;

v) use all relevant baseline data (including FORRU-CMU plot data) to determine suitable species and methods for the restoration of identified offset sites (it is likely that the framework species method, developed for forest restoration on the mine pits will be suitable);

vi) include appropriate stakeholders in participatory monitoring of the biodiversity offset sites to strengthen boundaries of responsibility and create credibility in the effectiveness of offsets actions and long-term outcomes;

vii) use the monitoring procedures described in Section 8 to track biodiversity recovery in offset sites;

viii) support the park authority in protecting biodiversity-offset sites for an appropriate period of time following restoration, particularly fire prevention and cattle exclusion.

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8 MONITORING

The main aim of biological rehabilitation at the SCG Lampang Limestone Quarry is restore ecosystem levels of biomass, structural complexity, biodiversity and ecological functioning to those typical of the original reference forest ecosystem, in this case the conservation forest areas. Data are collected in:

Monitoring determines the extent to which restoration achieves reference conditions.

i) small control plots (**origin**) (which are left untreated, to determine the extent to which natural recovery occurs),
ii) rehabilitation plots (**treatment**) and
iii) reference forest plots (**target**)

Monitoring is performed in origin, treatment and target plots, both before and after treatments are implemented.

… with data collected just before and after interventions are initiated (baseline) and at appropriate intervals thereafter until self-sustainability is achieved. Sampling effort and measurements made should be identical in all 3 areas. Comparing i) and ii) determines the effectiveness of interventions above what could be achieved solely by natural recovery, whilst comparing i) and iii) tracks the progress of restoration towards the ideal end-state.

Baseline data of pre-mining conditions provide the starting point, whilst the reference provide the target conditions. Monitoring assesses the extent to which restoration moves the ecosystem from the starting conditions to the target conditions.

Since rehabilitation takes a long time, the monitoring plan should comprise both short term and long-term actions:

Monitoring includes both short-term and long-term actions.

i) Short-term monitoring (initial establishment monitoring): in the first 2 years of initiation of restoration activities focusses on determining if restoration tasks have been properly implemented e.g., survival and growth of newly planted trees.
ii) Long-term monitoring: beginning 2–3 years after restoration initiation tracks the progression of rehabilitation along long-term trajectories and whether or not those trajectories are likely to deliver a sustainable ecosystem in the long run.

8.1 VEGETATION

8.1.1 CIRCULAR PLOT SURVEYS

10-m-diameter circular sample plots are ideal for vegetation monitoring.

Circular sample units (SU's) 10 m in diameter have become the international standard for monitoring vegetation recovery as a result of restoration activities. SU's are evenly positioned across sites and surveyed just after tree planting and at the end of each rainy season to determine which tree species grow well and how quickly forest structure recovers. A minimum of 10 SU's should be positioned across each of the 3 sites (control, restoration and reference sites). A wrought iron pole (which will survive fire) marks the centre of each circular SU and a 5-m-long piece of string (tied to the centre pole) is used to delineate the SU circumference. Coloured tape and an indelible pen are used to apply an identification number to each pole. The GPS location of each pole is recorded and the trees (both planted and natural) in each circle are counted and labeled thus:

Count and label all trees taller than 50 cm in each plot.

i) Saplings (taller than 50 cm but GBH <5cm (girth at breast height @1.3 m above ground level) are labelled with aluminium strips (bindings for electrical cables), stamped with an ID number and formed into rings around tree stems.

ii) For larger trees and stumps, square labels made from drinks cans are used to mark the point 1.3 m from the base of the tree, where GBH is measured.

Record tree height, root collar diameter or GBH, health score, weed cover score and shade score.

The following data are recorded for each labelled tree (both natural and planted) in each circle:

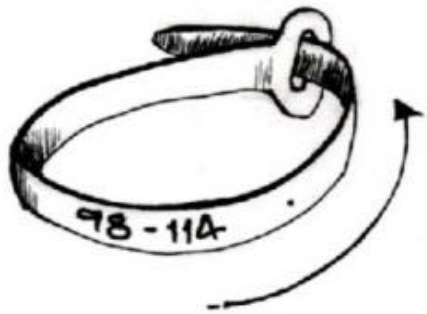
i) tree height (cm) (from root collar to highest apical bud) using a tape measure or telescopic measuring pole for smaller trees and digital clinometer for taller trees,

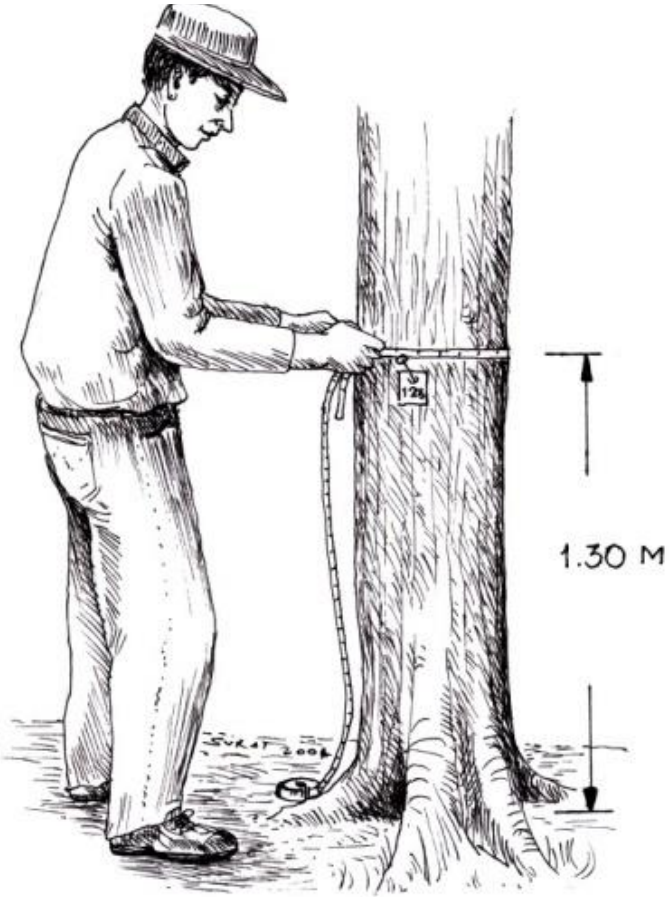
ii) root collar diameter (mm) for small trees using digital calipers or GBH (cm) for larger trees (of GBH>5 cm) with a tape measure),

iii) health score,

iv) weed cover score and

v) shade score.





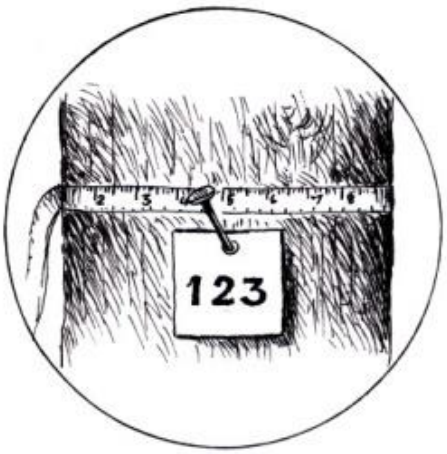


Figure 8.1 - Tree labelling

Figure 8.2 – Digital callipers

For small trees, measure root collar diameter (RCD) at the widest point with digital calipers. Once a tree has grown tall enough to develop a GBH of 5 cm or larger, measure both the RCD and the GBH (1.3 m from the ground), the first time and only GBH thereafter. Because RCD is a small value, it must be measured with high accuracy. For best results, measure RCD twice by turning the calipers at right angles and then use the average reading.

Figure 8.3 – Measuring crown width (left) and tree height with telescopic pole (right).

Assign a simple health score (0-3) to each tree and record descriptive notes about any particular health problems observed. Score zero if the tree appears to be dead. For deciduous tree species, don't confuse a tree with no leaves in a dry season with a dead one. Do not stop monitoring trees just because they score zero on one occasion. Many trees, which appear dead above ground, may still have living roots, from which they may subsequently re-sprout new shoots. Score 1 if a tree is in poor condition (few leaves, most leaves discoloured, severe insect damage etc.). Score 2 for trees showing some signs of damage but retaining some healthy foliage. Score 3 for trees in perfect or nearly perfect health. Measure the width of the tree crown (cm) at the widest part with a tape measure.

Data Sheet for circular plot monitoring

SAMPLE UNIT ID #:	RECORDER:			ANR OR CONTROL		DATE:	
Within 5 m radius circle							
Label	**Tree Species**	**Height** (cm)	**RCD** (mm)	**GBH (cm)** if >5 cm	**Health Score** 0-3	**Crown Width** (cm)	**No. Coppicing Shoots** (for tree stumps)	**Notes**
	Local ..... Sci.							
	Local ..... Sci.							
	Local ..... Sci.							
	Local ..... Sci.							
	Local ..... Sci.							
	Local ..... Sci.							
	Local ..... Sci.							
	Local ..... Sci.							
	Local ..... Sci.							

Series of pictures taken over time show the development of the rehabilitation area.

8.1.2 GROUND PHOTO MONITORING

Photo monitoring provides a quick and easy visual representation of how quickly forest cover and structure return following restoration operations. A series of pictures at the same point, taken over time is often more effective at raising public support than tables or charts of data.

Take 4 photos, looking out from the pole that marks the centre of each sampling plot, roughly towards N, W, S and E (in that order). Set the camera to the widest possible zoom setting and the highest resolution. Frame each picture to include the top of the pole (showing the pole i.d. number and direction mark) in the lower right-hand corner. Use a compass to record the direction of the photo. Keeping the top of the pole in the lower right-hand corner of the picture, gradually tilt the camera down to minimize the amount of sky in the shot, so the horizon should be near the top edge of the picture. Use the same camera with the same zoom and resolution settings for all photos. Transfer photos to a computer as soon as possible and rename the files as follows: pole reference number_date (yymmdd), e.g., ML3E_170315 (sample plot no. 3 at the at Mon Long site (ML) facing east, taken on 15th March 2017)).

Figure 8.4 – Ground photo monitoring; take photo photos looking out from the pole that marks the centre of sampling plot to 4 different directions

8.1.3 MONITORING BY DRONE

Aerial photos, showing the overall recovery of a site from above are even more effective at demonstrating habitat restoration. Using software, such as Litchi, a drone can be programmed to take aerial photos from exactly the same points in three-dimensional space every time monitoring is carried out. That will provide the information of changing of restoration plot vegetation structure. For example, the data from drones can be used to analyse trees height, percentage cover that changes over time. However, using drones requires training and technical know-how.

Figure 8.5 – Drone equipped with a camera can be used for restoration progress monitoring.

8.1.4 FOREST PROFILES

The development of structure complexity in restored forests can be determined by forest profile diagram. The data from profile diagram also use to perform crown density analysis to identify the existence of canopy layers.

To create forest profile diagram, lay out a tape measure 40 m in a straight line. To each tree less than 3 m from the tape measure on both sides (i.e., transect width is 6 m) attach a numbered metal label. Measure the circumference (or GIRTH) of each tree at exactly 1.3 m from the base (GIRTH AT BREAST HEIGHT GBH).

Stand UPHILL from the base of each tree where you can see the top of the canopy. Make sure that the top of the tree and the lowest branch are HIGHER THAN EYE LEVEL and the base of the tree is LOWER THAN EYE LEVEL. Measure the distance from the base of the tree to your

eyes. Make sure that this distance is more than 10 m for small trees and more than 20 m for tall trees. With the clinometer, measure the angles (degrees deviation from the horizontal) of "B°" (angle to the base of the tree), "T°" (angle to the top of the tree and "LB°" (angle to where the lowest branch joins the trunk of the tree).

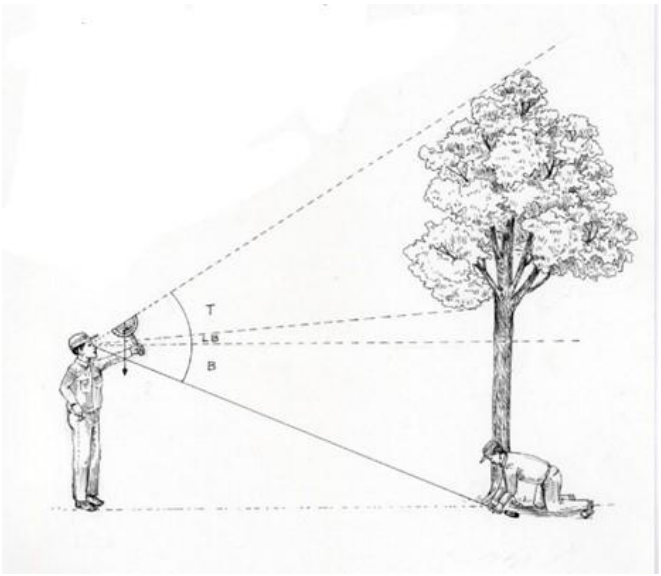


Figure 8.6 – Use a clinometer to measure the angles of lowest branch, top and base of the tree to calculate tree height.

Calculate tree height and lowest branch height from these equations: -

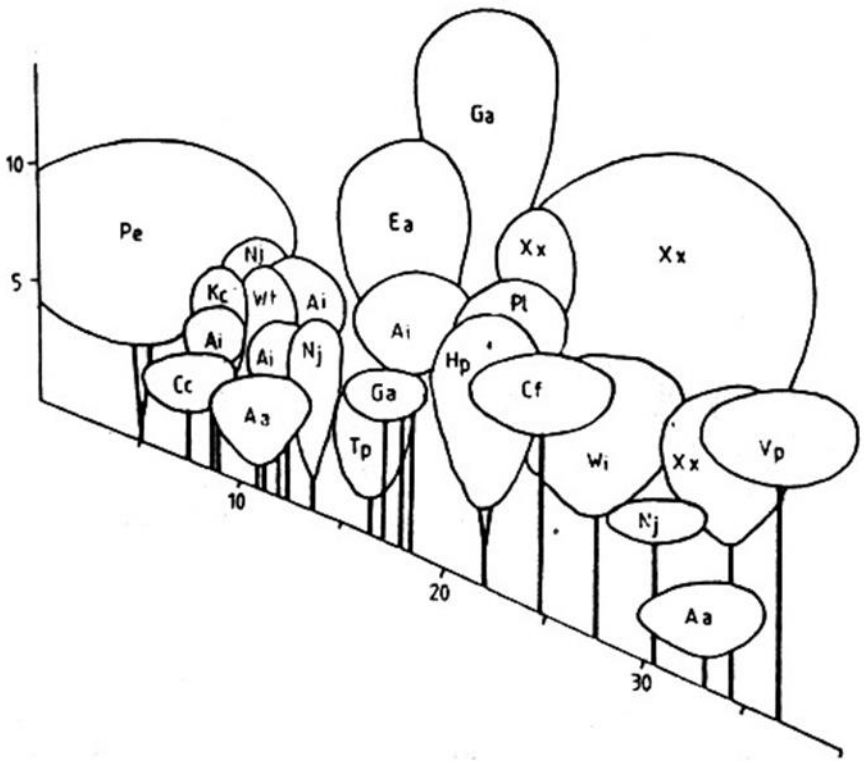
B	=	angle to base of tree
T	=	angle to top of tree
LB	=	angle to lowest branch
DBE	=	distance from base of tree to eyes of observer
SQRT	=	square root of [....]

TREE HEIGHT = (sin B x DBE) + (tan T x SQRT [DBE^2 – (sin B x $DBE)^2$])

LOWEST BRANCH HEIGHT = (sin B x DBE) + (tan LB x SQRT [DBE2 – (sin B x DBE)2])

Estimate the crown length, parallel to the direction of the profile. Use the clinometer to measure the slope of the ground.

Construct a profile diagram like the example shown below. Use the same scale for the vertical and horizontal axes. Indicate the species of trees where known.



Profile diagram of the M_1 sub-association at quadrats 3 – 4. Aa, *Antidesma acidum;* Ai, *Anacolosa ilicioides;* Cf, *Colona flagrocarpa;* Cr, *Cratoxylum cochinchinensis;* Ea, *Eugenia albiflora;* Ga, *Gmelina arborea;* Hp, *Holarrhena pubescens;* Kc, *Kydia calycina;* Pl, *Phoebe lanceolata;* Nj, *Nyssa javanica;* Pe, *Phyllanthus emblica;* Tp, *Turpinia pomifera;* Vp, *Vitex peduncularis;* Wi *Walsura intermedia;* Wt, *Wendlandia tinctoria*; Xx, *Xylia xylocarpa.*

Figure 8.6 – The profile diagram demonstrates the forest structure in the area.

1. Plot a graph of tree height vs. circumference. Calculate the regression coefficient R^2 to determine if it is possible to predict tree height by measuring GBH.

2. Draw a histogram to illustrate how canopy density varies from ground level upwards. Select all trees which have a lowest branch height less than 2 m and tree height higher than 2 m. Sum their canopy lengths and divide the sum by the length of the profile. Repeat for 4 m height, 6 m height etc. up to the height of the highest tree and present your data as a horizontal histogram like the example provided below. A mean canopy density of <1 indicates incomplete canopy closure whereas >1 indicates complete canopy closure. Layers in the canopy are indicated by dips in canopy density in-between peaks.

3. Draw a histogram to present the size distribution of the trees. A "J" curve indicates a healthy regenerating forest.

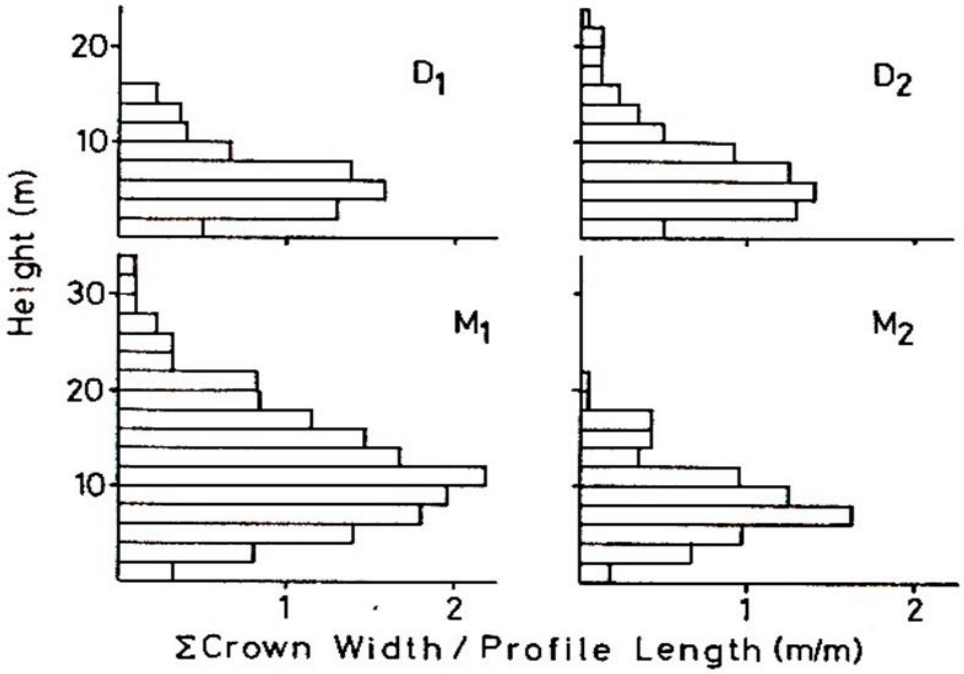


Figure 8.7 – Histogram illustrates the canopy density variation from ground level to top of the canopy

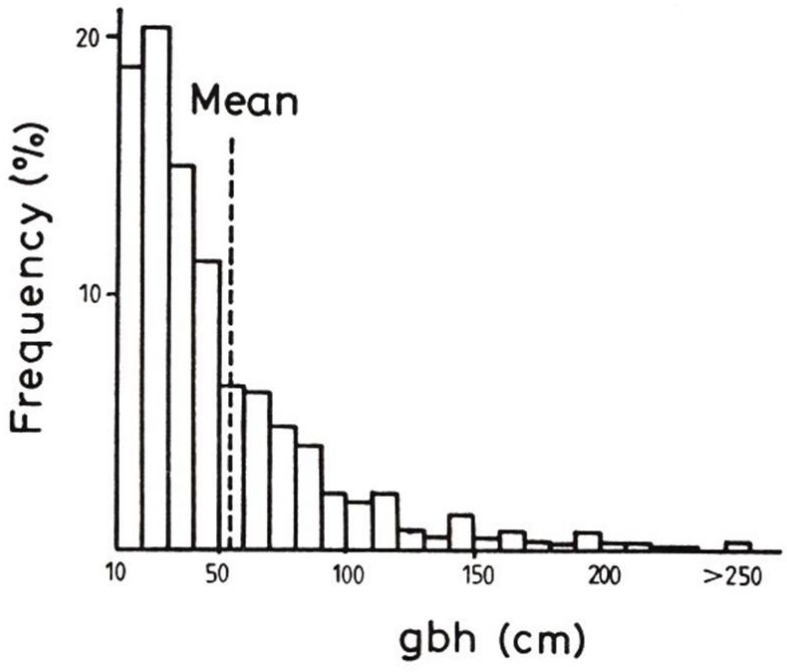


Figure 8.8 – Histogram of tree size distribution, J-shape distribution indicate forest regeneration.

8.1.5 GROUND FLORA SURVEY

After mining the area is severely degraded; no topsoil, low nutrient content, no organic matter. That harsh condition is not suitable for plant growth. Planting trees in the rehabilitation process will increase tree crown cover which creates a more suitable condition for herbaceous and plant seedlings. The recovery of ground flora can be used to determine the succession of plant communities in the area. The reestablishment of tree seedlings will indicate that the natural regeneration process is taken place.

To survey ground flora community, use the same SU's used for the trees, first estimate gross structural composition, including coverage of the SU by rock, bare soil, leaf litter, all grasses, all other herbs, shrubs and tree crown cover. Use the Braun-Blanquet Score to categorize the estimated cover.

Ground flora community can be surveyed within the same sample unit as tree.

Braun-Blanquet Score	
Sparsely or very sparsely present, cover very small	0.1
Plentiful, but of small cover value	1
Very numerous or covering at least 5% of area	2
Any number of individuals covering 1/4 to 1/2 of area	3
Any number of individuals covering 1/2 to 3/4 of the area	4
Covering more than 3/4 of the area	5

Next use the same scoring system to estimate the cover of each herbaceous species and the presence of any small tree seedlings i.e., those shorter than 50 cm and therefore not included in the tree survey. Record vernacular species names, provided by local community members, and work with a botanist to obtain scientific names. Use the format in Data Sheet on the next page to record the ground flora data.

Data Sheet – Ground Flora

SAMPLE UNIT ID #:	Date:	RECORDER:
Ground Flora Within 5-m Radius Circle		
Feature	**SCORE**	
Rock		
Bare soil		
Leaf litter		
Grass		
Total other herbs		
Tree crown cover		
SPECIES	**SCORE**	**Tick if tree**
Local		
Sci.		
Local		
Sci.		
Local		
Sci.		
Local		
Sci.		
Local		
Sci.		
Local		
Sci.		
Local		
Sci.		
Local		
Sci.		
Local		
Sci.		
Local		
Sci.		
Local		
Sci.		
Local		
Sci.		
Braun-Blanquet Score		
Sparsely or very sparsely present, cover very small	*x*	
Plentiful, but of small cover value	*1*	
Very numerous or covering at least 5% of area	*2*	
Any number of individuals cover 1/4 to 1/2 of area	*3*	Page No.
Any number of individuals covering 1/2 to 3/4 of the area	*4*	
Covering more than 3/4 of the area	*5*	

8.1.4 Vegetation diversity

To determine tree diversity in the rehabilitation area, construct species/area graphs using Coleman's equation (Hubbell and Foster, 1983):

$$s_{(a)} = S - \sum_{i=1}^{S} (1 - a)^{n_{(i)}}$$

… where $s_{(a)}$ is the expected number of species in a fraction (a) of the total area surveyed (i.e., a=0-1), S is the total number of species encountered and $n_{(i)}$ is the number of individuals of each species over all ten plots (i.e. i=1 to S). The equation is solved for different values of 'a' and the resulting curve of s(a) vs. 'a' is plotted.

These curves can be plotted for both the reference forest and the rehabilitation plot and forest, at the beginning of the rehabilitation process and after. It is expected that, between the first and subsequent monitoring events, the curve will rise in the rehabilitation plot, due to natural regeneration that add up species into the area. However, it will take a long time before natural seedlings will regenerate into the area.

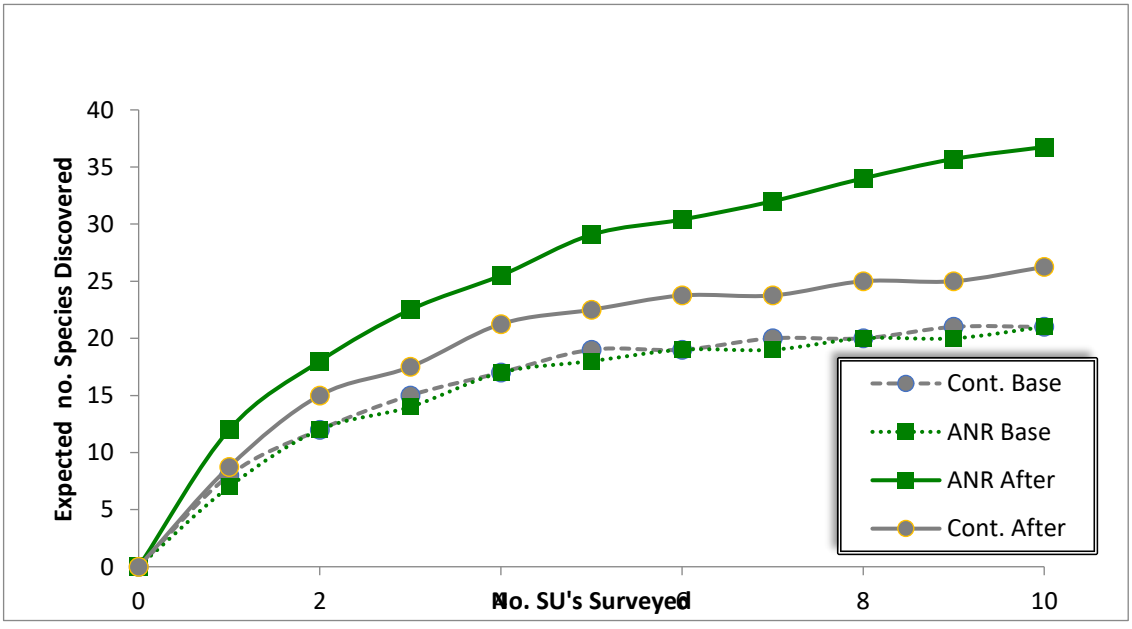


Figure 8.9 – Species/area curves construct by Coleman's equation.

This result can be confirmed by calculating Hill's Diversity Numbers (N0, N1 and N2) (Ludwig and Reynolds, 1988), which should also increase over time in the rehabilitation site.

N0 = no. of species (species richness)

$N1 = 2.71828^{H}$

... where $H = \text{minus} \sum_{i=1}^{S} [(p_i) \times \ln(p_i]$

$$N2 = \frac{1}{\sum_{i=1}^{S} (\text{pi})^2}$$

... where p_i is the number of individuals of each species (or Braun-Blanquet score) as a proportion of total number of individuals (or Braun-Blanquet score) of all species in all SU's in each site. Example calculation is below.

	Number of individuals or score					
	n(i)	**pi**		**pilnpi**		**pi^2**
Species A	1	0.053		-0.155		0.003
Species B	2	0.105		-0.237		0.011
Species C	4	0.211		-0.328		0.044
Species D	1	0.053		-0.155		0.003
Species E	3	0.158		-0.291		0.025
Species F	1	0.053		-0.155		0.003
Species G	2	0.105		-0.237		0.011
Species H	1	0.053		-0.155		0.003
Species I	1	0.053		-0.155		0.003
Species J	2	0.105		-0.237		0.011
Species K	1	0.053		-0.155		0.003
Total individuals (N)	19	1	H	2.26	LAMBA	0.12
N0	**11**		**N1**	**9.59**	**N2**	**8.40**

The successful effects of rehabilitation would also be indicated by a significantly larger increase, over time, in the mean per cent cover values of leaf litter, shrubs and tree crowns in the rehabilitation site. And increasing of similarity of vegetation between rehabilitation area and reference forest.

8.1.5 Similarity index

A similarity index can determine how closely the current plant community resembles the community in the referent forest. The Similarity Index is expressed as a portion of the reference community that is currently on a restored site.

One of the simple similarity indexes that can be used with the qualitative data is the Sørensen similarity index. The formula for the index is:

$$QS = \frac{2C}{A+B}$$

… where A and B are the species numbers in sample A and B, respectively, C is the number of species shared by the two samples

The Sørensen similarity index can be used for both vegetation and animal community.

Action points:

i) set up the circular plot system in the reference forest and every restoration plot for monitoring purposes
ii) label all seedlings and trees in circular plots (both planted and natural ones), calculate the diversity index, compare the similarity between reference forest and restoration plots and re-survey that every 2 years
iii) take pictures for ground picture monitoring at each circular plot before and after rehabilitation every time along with vegetation survey
iv) set up the system for ground picture monitoring by drone for the whole rehabilitation area monitoring, and
v) Set up permanent transect for forest profile study, which use for forest structure development monitoring.

8.2 BIRDS

Birds are important seed-dispersers and indicators of biodiversity.

Wildlife species that return to the rehabilitation area contribute to biodiversity, but seed-dispersing animals can accelerate biodiversity recovery more than other species. Bird is one of the important groups of seed-dispersers in forest ecosystem. They also provide a convenient indicator group for the evaluation of biodiversity because:-

i) They are relatively easy to see and most are easy to identify.
ii) Many excellent identification books and audio guides are available.
iii) Most species are active by day.

Birds occupy most trophic levels in forest ecosystems –herbivores, insectivores, carnivores etc. and therefore, a high diversity of birds usually indicates a high diversity of plantsand prey species, especially insects.

8.2.1 FIELD SURVEYS

The bird surveys should be carried out before rehabilitation process both in reference forest and rehabilitation plots as a baseline data. The data from the remnant forest (reference forest) also provides data on the richness and composition of the "target" bird community. Thereafter, carry out bird surveys with the same intensity in both planted plots and the nearest area of remnant forest.

Morning and evening are the best times to survey bird diversity.

Annual bird surveys are usually sufficient to detect changes in bird communities. Carry them out at the same time each year, since bird species richness fluctuates according to seasonal migration patterns. Observe birds during the first 3 hours after dawn and the last 3 hours before sunset. Timetable 1 hour observation periods in each plot, alternating around the plots at hourly intervals, but ensure that, over the entire survey period, all plots are studied for the same number of hours, spread evenly among morning and evening observational periods. Use binoculars to spot the birds and a bird guidebook to identify them. Record all bird observations on the standard data collection sheet.

Use the "point count" method to count birds from the centre of each plot. This method can be used to both count species and estimate bird population density (Gibbons et al., 1997 and Bibby et al., 1998). Stand

in the centre of each plot and record all bird contacts for 1 hour by both sight and song. Record the species and numbers of birds and estimated distance from the observer when birds first appear in the plot. To reduce the risk of recording the same individual birds, several times, do not record the same bird species entering the plot for five minutes after first recording that species. Record the tree species (and tree number if labeled), in which birds have any activity (particularly feeding) and their position (trunk, lower canopy, upper canopy etc.).

Bird Survey Record Sheet

File Name:	Restoration Plot 6 years old

Date: 17.12.05 Weather: sunny, cool Recorder/s: LM, MT, CT

Block Number: G1 Plot Number: EG-05

Start time: 7.47am Finish time: 10.30 am

TIME	SPECIES(COMMON NAME)	SONG OR SIGHT	NO. OF INDIVIDUALS	DISTANCE FROM POINT (M)	TREE (SPECIES/ LABEL)	POSITION (CROWN/ TRUNK ETC.)	ACTIVITY (FEEDING, PERCHING, DISPLAYING ETC.)
7.47	Black-crested Bulbul	sight	1	20	Eyrthrina stricta	crown	feeding and flying
7.52	Bar-winged Flycatcher-shrike	sight	5	30	Ficus altissima	crown	feeding and flying
8.06	Hill Blue Flycatcher	song	1	50	Betula alnoides	tree trunk	flying
8.08	Sooty-headed Bulbul	song	1	25	Gmelina arborea	crown	flying
8.15	Puff-throated Babbler	sight	2	15	Spondias axillaris	tree trunk	flying
8.23	White-rumped Shama (male)	sight	1	10	near Prunus cerasoides	ground	perching

Scanning the species lists and counting the number of bird species that recolonize the plots and those that disappear as a result of forest restoration activities.To calculate the extent of recovery in the bird community, compare the species lists for remnant referent forest and planted plots. Calculate the percentage of the species found in forest that are also found in the restored plots and look at how this percentage changes over successive survey times. Next, determine which of those species are frugivorous. These are the critical species most likely to disperse seeds from forest into planted plots.

Use the MacKinnon list method for quantitative analysis of bird species richness biodiversity.

For quantitative analysis of the species richness of bird communities, "MacKinnon list method" is recommend. This method uses the "list" as the unit of effortto construct a species-discovery curve. The method is relatively insensitive to differences in the ability of observers. Moreover, it produces similar results during periods of high or low activity. Arrange the datasheets from the field survey in order of time and then make a list of the first 10 DIFFERENT bird species that you saw down the left-hand column on a table. Continue scanning the data sheets and in the second column of the table make a second list of 10 species, just as before. If you recorded a species already recorded in the first list, place a cross against its name in column 2. If you saw a species not already recorded in the first list, then add its name to the bottom of the species list. Repeat this process until you have ten lists. On any one list, each species occurs only once, but a single species may occur on more than one list or even on all of them.

McKinnon Bird Species List - 6 year old Restoration Plot

		List Number										No. of lists on which the species occurs
		1	2	3	4	5	6	7	8	9	10	
1	Black-crested Bulbul	√			√	√	√		√	√		6
2	Bar-winged Flycatcher-shrike	√	√						√			3
3	Hill Blue Flycatcher	√		√	√	√		√		√	√	7
4	Sooty-headed Bulbul	√				√	√					3
5	Puff-throated Babbler	√	√	√								3
6	White-rumped Shama	√							√	√	√	4
7	Yellow-browed Warbler	√			√		√	√	√			5
8	Golden Spectacled Warbler	√	√	√	√		√	√		√	√	8
9	Golden-fronted Leafbird	√										1
10	Verditer Flycatcher	√				√					√	3
11	Lesser Necklaced Laughing thrush		√									1
12	Long-tailed Minivet		√	√		√		√		√		5
13	Green-billed Malkoha		√						√			2

The total number of bird species seen (by making ten lists) can be used as a reliable index of the bird community species richness.

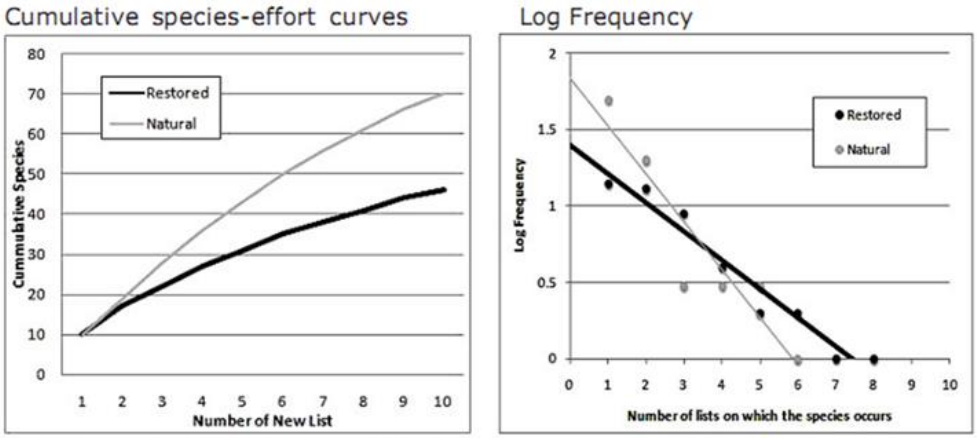
- Count the numbers of new species found in each list and fill in the row marked "NO. OF NEW SPECIES".
- Accumulate the no. of new species in the bottom row of the table, e.g., the value for list no. 3 would be no. new species in list 3 + no. new species in list 2 + no. of new species in list 1. Plot a

graph of cumulative no. of new species along the y axis and no. of lists along the x axis.

- Fill in the far-right column on the data sheet marked "NO. OF LISTS ON WHICH SPECIES OCCURS" and fill in the table below:

NO. OF LISTS ON WHICH SPECIES OCCURS	1	2	3	4	5	6	7	8	9	10
NO. OF SPECIES OCCURRING ON THAT NO. OF LISTS (FREQUENCY)										
LOG_{10} FREQUENCY										

- Plot a graph of log frequency along the y axis and no. of lists on which species occur along the x axis.
- Extrapolate the line back to zero. Where the line crosses the y axis gives an estimate of the log no. of species not seen during the survey. Convert this log value into a number using antilog and add the result to the total number of species seen to obtain an estimate of the total number of birds in the community.



Extract the numbers of observed species from the species-effort curves (70 and 46 for natural "target" and restored forest respectively, above left). Plot the log frequency graph (right). Extrapolate the line-of-best-fit back to zero and read off the log values for the no. of species *not* observed. Convert the logs into numbers (1.84 and 1.40 = 69 and 25 species respectively). Add that number to the number of observed species, to arrive at an estimate of the total number of bird species in the community (139 and 71 species respectively).

Action points:

i) survey bird community in reference forest (target community and mining area as baseline data
ii) after rehabilitation survey bird community in the restored area annually (at the same time each year) to monitor the change and compare the similarity between rehabilitation site and target community in the reference forest.

8.3 Mammals

Fruit eating and seed predating mammals are of main interest for ecological restoration.

For mine rehabilitation mammals can be divided into two groups of interest: i) fruit eating species, capable of dispersing seeds from the intact forest into restored sites (e.g., large ungulates, civets, fruit bats and so on) and ii) seed predators, which may limit the establishment of recruit tree seedling species in restored sites (particularly small rodents).

Compared with birds, they are far more difficult to survey, since most species are nocturnal and very shy, so direct observations of mammals are usually few and far between. Opportunistic, anecdotal data, are more commonly used to determine the recovery of mammal communities after forest restoration (rather than systematic, quantitative data).

8.3.1 CAMERA TRAPPING

Camera traps can be used to survey mammals in the reference forest and rehabilitation area.

For larger, non-bat, species camera trapping is a very effective way of determining the presence of mammal species in an area. The camera should be set in both rehabilitation sites and reference forests. Use the camera with a motion sensor to capture wildlife.

Some suggestions for camera trap setting

Before turning on the camera, always check that the memory card is properly stored. Make sure that the proper card is inserted into the camera, for example, camera 2 should have the camera 2 memory card. This way all pictures downloaded from the memory card are matched with the proper location. Check that the date/time on the camera is correct. Verify the batteries have at least 30% remaining, if

less than 30% please change the batteries. Record the GPS coordinates of the camera.

Placing cameras where the possibility to see wildlife is high i.e., along animal trails, at mineral licks or water holes, or attract animals to the camera location with a lure. Avoid areas with thick ground vegetation, to get a clear area for the picture. Put the camera into the protection box and secure it at about knee height on the tree. When the camera is in a position do a test by waving your hand in the desired place that you hope to capture on the camera. When the camera has detected movement, a red light on the front of the camera will flash.

Run the camera for 3-4 weeks before retrieving the data from the memory card. Record the animal that captures and identify them from field guides (Francis & Barrett, 2008).

กระรอกท้องแดง

(Callosciurus erythraeus)

ลิงวอกภูเขา

(Macaca assamensis)

อีเห็นข้างลาย

(Paradoxurus hermaphroditus)

แมวดาว

(Prionailurus bengalensis)

Action points:

i) survey mammal community in reference forest (target community and mining area with camera trap as baseline data
ii) use camera traps to monitor mammal community in the restored area to determine the change and compare the similarity between rehabilitation site and target community in the reference forest.

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9 OPPORTUNITIES FOR EDUCATION AND OUTREACH

Since 1994, the Siam Cement Lampang Co. Ltd. work according to their policy "Create jobs, create prosperity and be a good citizen of Lampang" (สร้างงาน สร้างความเจริญ และเป็นพลเมืองที่ดีของลำปาง). The mining activities were well planned and managed to minimize the effects on the communities and environment. The rehabilitation process was undertaken along with mining activity. The company rehabilitated the area with the objective to return forest back to the area. In 2012, the mine began cooperation with the Forest Restoration Research Unit to develop mine rehabilitation strategies to restore the ecosystem back to the condition that is similar to the original ecosystem.

The Siam Cement Lampang Co. Ltd. would like to be the leader in limestone mine rehabilitation in Northern Thailand and serve as a good practice example for other mining companies. Various surveys and research were conducted to gain information about environmental conditions and biodiversity status of the company's area. This provided necessary baseline data for the management and rehabilitation plant.

10.1 SIAM CEMENT LAMPANG MINE REHABILITATION STUDY CENTRE

10.1.1. REHABILITATION KNOWLEDGE TRANSFER

The Siam Cement Lampang Mine Rehabilitation Study Center was established in February 2018 with the main objective to disseminate information about mine rehabilitation from SCG experience to the public. The target visitors of this center range from students, mine operators to government officers.

Knowledge on mine rehabilitation is transferred from SCG to public through the Mine Rehabilitation Study Center.

The exhibition includes information about mining management and rehabilitation strategies. The tree nursery which produces seedling for mine rehabilitation is also act as a part of the exhibition. The visitors could also visit mixed deciuous forest and learn about forest ecosystem along the nature trail.

Figure 9.1 Siam Cement Lampang Mine Rehabilitation Study Centre, routine work on seedling production processes from phenology study, seedling propagation and seedling care are demonstrated as part of the exhibition.

10.1.2 LITTLE GUIDE PROJECT

The Siam Cement Lampang set up a cooperation project "Little Guide" with the local schools and community. The students from Ban Pan school, Chumchon Ban Sa School and Jae Hom Wittaya school (โรงเรียนบ้านแป้น โรงเรียนชุมชนบ้านสา และโรงเรียนแจ้ห่มวิทยา) were educated and trained to be the guides for Rehabilitation Study Center. The little guides can lead the tour in 3 languges; Thai, Northern dialect and used in the acThis activity also rise their awareness about the important of rehabilitation and biodiversity conservation.

Figure 9.2 Little Guide of The Siam Cement Lampang Mine Rehabilitation Study Center.

ACTION POINTS:

i. Maintain the activities in the Siam Cement Lampang Mine Rehabilitation Study Center for seedling production
ii. provide educational activities and continue the cooperation with the local schools.

10.2 RESEARCH ON MINE REHABILITATION

Rehabilitation areas are valuable for further education in mine restoration.

The Siam Cement Lampang is determined to restore the area after mining to become a complete ecology again. The company has collaborated with various agencies such as WWF, Forest Restoration Research Unit, Chiang Mai University and Rajamangala University of Technology Lanna Lampang, in order to explore the biodiversity in the company's area and develop effective methods of mine rehabilitation.

Various researches were done by researchers, bachelor and graduated students in the area. The site preparation methods were tested. Different tree species were tested in to select the suitable species for mine rehabilitation (FORRU, 2015). Microorganismm were tested to study the effects on performance of tree seedlings (Detkrut, 2015). Tree performance and biodiversity recovery were monitored. The information gained from the studies are used to develop more efficient methods for mine rehabiliattion. This makes Siam Cement Lampang become an important learning area about post-mining rehabilitation and at the same time Siam Cement Lampang will gain the benetit in term of knowledge for mine rehabilitation.

Action point:

i. cooperate with the educational institutions to develop in-depth research and improve rehabilitation practice

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10 IMPLEMENTATION

The table below shows the activity required for biodiversity management in SCG Lampang. The number in a blanket at the end of each activity indicates the chapter and section of this report that explain that activity in detail. (Example: 5.1 is Chapter 5 section 5.1)

Activity	Year							
	1	2	3	4	5	6-10	11-15	16-20
AVOIDING OR MITIGATING HABITAT LOSS OR DEGRADATION								
Maintain site security, prevent encroachment, and exclude livestock								
- Review mine security procedures at appropriate intervals and implement improvements when necessary (section 5.1)	X		X		X	X	X	X
- Inspect the security fences and carry out repairs where necessary (section 5.1)	X	X	X	X	X	X	X	X
Prevent fires								
- Appoint an officer to monitor the occurrence of fires within 10 km of the mine, using NASA's Fire Information and Resource Management System (FIRMS) twice daily throughout the fire season-and report fires moving towards the mine to senior staff, to alert and mobilize fire suppression crews. (section 5.2)	X	X	X	X	X	X	X	X
- Maintain a fire tower in the center of the largest preserved forest area, equipped with a drone, to track on-	X	X	X	X	X	X	X	X

Activity	Year							
	1	2	3	4	5	6-10	11-15	16-20
coming fires and coordinate fire-fighting as necessary. Appoint staff to man the tower during the fire season 24 h/day. (section 5.2)								
- Implement a messaging system to call into service a fire-fighting team when needed. (section 5.2)	X	X	X	X	X	X	X	X
- Train and maintain a team of SCG staff, capable of safely tackling forest fires. (section 5.2)	x			x		x	x	x
- Assign staff members to be "on-call" for fire suppression duties using a rotating system throughout the fire season. (section 5.2)	X	X	X	X	X	X	X	X
- Maintain a stash of fire-fighting equipment on-site and place barrels of water at strategic points around the conservation and buffer forest areas in advance of the fire season. (section 5.2)	X	X	X	X	X	X	X	X
- Train and support train local people in fire prevention and fire fighting in neighboring communities. (section 5.2)	X			X		X	X	X
Habitat conservation								
- Reverse and prevent the invasion of forest areas by invasive exotic plant species (section 5.3, 6.1).	X	X	X	X	X	X	X	X
- Ensure that no further forest clearance is performed to establish mine buildings and/or infrastructure during the remaining phases of mine operation; place any such infrastructure needed on former pit areas or where the forest has already been cleared section 5.3	X	X	X	X	X	X	X	X
- Annually verify the maintenance of existing forest cover, using satellite imagery or drones and (section 5.3)	X	X	X	X	X	X	X	X

Activity	Year							
	1	2	3	4	5	6-10	11-15	16-20
- Dredge artificial ponds periodically, to maintain aquatic habitats for amphibians and water supply for wildlife. section 5.3	X			X		X	X	X
RESTORE FORESTS AND MAINTAIN AND INCREASE CONNECTIVITY AMONG FOREST PATCHES								
Keep the seed and seedling from the forest								
- When clearing area for new Pit, transfer topsoil to forest restoration plots —if applicable (section 5.4)	X	X	X					
- Transfer tree seeds/seedlings from the new Pit area to restoration plots —if applicable (section 5.4)	X	X	X					
Tree nursery								
- Continue monthly phenology monitoring in the buffer zone and conservation forest. (section 5.4)	x	x	x	x	x	x	x	x
- Continue to maintain an on-site tree nursery for planting stock production (section 5.4)	x	x	x	x	x	x	x	x
- Consider adding a seed bank facility to the nursery to store seeds in excess of current needs for future use (section 5.4)	x	x						
Restoration plots								
- Position restoration plots to maximize connectivity, between existing and restored forest patches; establish a corridor to link the preserved forest areas to the block between Pits (section 5.4)	x		x		x	x	x	x
- Restoration plots preparation: establish terraces (benches), 3-5 meters wide, as restoration plots in the pits apply 1 m. of topsoil (section 5.4)	x	x	x	x	x	x	x	x

Activity	Year							
	1	2	3	4	5	6-10	11-15	16-20
- Plant saplings of 20-30 framework tree species; 500/rai, following standard procedures and using species previously recommended from field trials on the mine (section 5.4)	x	x	x	x	x	x	x	x
- Apply silviculture techniques for in field planted s care at least for at least two subsequent rainy seasons (section 5.4)	x	x	x	x	x	x	x	x
Monitor growth and survival of planted trees and biodiversity recovery								
Plant								
- Set up the circular plot system in the reference forest and every restoration plot for monitoring purposes (8.1)	x	x	x	x	x	x	x	x
- Survey and label all seedlings and trees in circular plots, calculate the diversity index, compare the similarity between reference forest and restoration plots, and re-survey that every 2 years (8.1)	x	x	x	x	x	x	x	x
- take pictures for ground picture monitoring at each circular plot before and after rehabilitation every time along with a vegetation survey (8.1)	x	x	x	x	x	x	x	x
- set up the system for ground picture monitoring by drone for the whole rehabilitation area monitoring, (8.1)	x							
- Continue ground picture monitoring by drone (8.1)		x	x	x	x	x	x	x
- Set up permanent transects for forest profile study, which use for forest structure development monitoring. (8.1)	x					x	x	x
Animal								
- Survey bird community in reference forest (target community) and mining area as baseline data (8.2)	x	x						

Activity	Year							
	1	2	3	4	5	6-10	11-15	16-20
- After rehabilitation, survey the bird community in the restored area annually to monitor the change and compare the similarity between the rehabilitation site and the target community in the reference forest (8.2)		x	x	x	x	x	x	x
- Survey mammal community in reference forest (target community) and mining area with camera trap as baseline data (8.2)	x	x						
- Use camera traps to monitor the mammal community in the restored area to determine the change and compare the similarity between the rehabilitation site and target community in the reference forest. (8.2)		x	x	x	x	x	x	x
Maintain existing aquatic habitats and explore potential to create new ones								
- Monitor water quality –for pollutants and silt load and take action to reduce siltation and deal with sources of pollution as needed, (section 5.5)	x	x	x	x	x	x	x	x
- Dredge the ponds, as needed, to reverse siltation and maintain open water of sufficient depth (section 5.5)	x			x		x	x	x
- Explore the possibility of creating a larger area of open water as a wildfowl sanctuary (section 5.5)		x	x					
SPECIES-FOCUSSED MANAGEMENT								
Control invasive exotic species								
Implement a comprehensive *L. leucocephala* eradication program.								
- Cut larger saplings or mature *L. leucocephala*; apply herbicide to the stumps. (section 6.1)	x	x	x	x	x			
- Eradicate *L. leucocephala* seed sources close to the restoration plots (section 6.1)		x	x					
- Monitor restoration plots closely for *L. leucocephala* infestation. (section 6.1)	x	x	x	x	x			

Activity	Year							
	1	2	3	4	5	6-10	11-15	16-20
- Remove *L. leucocephala* seedlings on restoration sites at 6-8-week intervals throughout the rainy season. (section 6.1)	x	x	x	x	x			
- if the prescribed treatments do not work, then perform experiments to develop more effective eradication treatments (section 6.1)			x	x	x			
- experiment with adding bamboos to the framework tree species planted as a natural way to prevent *L. leucocephala* infestation. (section 6.1)		x	x	x	x			
Monitor species of concern								
- **trees**: detect the locations of the tree species listed in table 6.1 during regular assessments of overall plant diversity; use drones to search for them when their crowns are most distinctive; record the GPS locations of the trees (section 6.2, 8.1)	x							
- **trees**: check the status of the tree species listed in table 6.1 annually (section 6.2, 8.1)		x	x	x	x	x	x	x
- **mammals**: use camera trapping to detect the presence of the mammal species listed in table 6.1 for estimations of population status and trajectories in the conservation and buffer zone forest (section 6.2, 8.3)	x	x						
- **mammals**: continue with camera trapping to monitor the population of listed in table 6.1 (section 6.2, 8.3)		x	x	x	x	x	x	x
- **birds**: run the annual bird surveys on the site and detect the two endangered bird species during study (section 6.2, 8.2)	x	x	x	x	x	x	x	x
- **reptiles**: use camera trapping and visual encounter surveys (VES) to detect reptiles in the area, particularly for the rare species, listed in table 6.1 (section 6.2, 8.3)	x	x						

Activity	Year							
	1	2	3	4	5	6-10	11-15	16-20
- perform annual VES assessments to monitor reptiles population (section 6.2, 8.3)		x	x	x	x	x	x	x
- engage SCG staff and visitors in incidental monitoring, by enabling them to identify the animal species, listed in table 6.1, and by encouraging them to report any sightings they have ("citizens' science") via a phone app. (section 6.2)	x	x	x	x	x	x	x	x
Conservation actions targeting species of concern								
Plants								
- **trees**: having located seed trees of the species listed in table 6.1 during monitoring (section 6.2), perform phenology studies, to determine optimum seed-collection time, and collect seeds from as many individual trees of each species as possible, to maintain genetic diversity; grow planting stock in the on-site nursery, (section 6.3.1)	x	x	x	x	x	x	x	x
- include saplings of the species listed in Table 6.1 amongst the framework species planted in restoration plots on the pits (section 6.3.1)	x	x	x	x	x	x	x	x
- donate excess seedlings of high-value "rosewood" timber species (*Dalbergia cochinchinensis*, *D. oliveri, Pterocarpus indicus* and *P. macrocarpus*) to local farmers to uplift and diversify local livelihoods, raise community support for maintaining the conservation forest and increase populations of these rare and declining species Indicus (section 6.3.1)		x	x	x	x	x	x	x
- **orchids**: instigate an orchid propagation and re-introduction program, in collaboration with QSBG or CMU to re-establish this highly speciose and ecologically functional plant group. Species recommended are listed in Table 6.2. (section 6.3.1)			x	x	x	x		

Activity	Year							
	1	2	3	4	5	6-10	11-15	16-20
Animals								
- continue to implement security measures to prevent hunting, (section 5.1, section 6.3.2)	x	x	x	x	x	x	x	x
- when the monitoring measures detect declines in animal species of concern, consider supplementary feeding programs, particularly during times of seasonal scarcity (dry season), (section 6.2, section 6.3.2)			x	x	x	x	x	x
- consider habitat manipulation to improve breeding requirements in situ (section 6.3.2)			x	x	x	x	x	x
- if populations continue to decline, consider establishing a captive breeding facility, particularly for the endangered and critically endangered reptiles (section 6.3.2)						x	x	x
- work with the DNP to re-introduce species from the captive breeding facility into Tum Pah Thai National Park, where their security is assured. (section 6.3.2)						x	x	x
Study the effects of dust and noise on forest ecosystems and wildlife								
- instigate a study to determine the effects of dust and mitigation measures on the primary production and biomass accumulation of vegetation, comparing roadside with forest-interior vegetation (section 6.4)	x	x						
- instigate a study on the effects of noise on bird behaviour, particularly nesting (section 6.4)			x	x				
- review and, if necessary, modify dust- and noise-mitigation measures on the mine, if these studies show a deleterious effect on plants and wildlife, particularly on the species of concern listed in table 6.1 (section 6.4)				x	x	x	x	x

Activity	Year							
	1	2	3	4	5	6-10	11-15	16-20
BIODIVERSITY OFFSET								
- restore 11.6 – 12.3 km^2 of bamboo-deciduous forest on former teak-plantation sites in Tham Pah Thai National Park, using the conservation forest on the mine as a reference forest type (section 7.3)	x	x	x	x	x	x	x	x
- ensure that the restoration project supports local and national conservation policies and targets (section 7.3)	x	x	x	x	x	x	x	x
- perform stakeholder consultations, to facilitate inclusive decision-making and to help define multiple benefits from offsets (section 7.3)	x			x		x	x	x
- perform offset actions to maximize habitat connectivity, both within the national park and between the park and buffer zone or conservation forest in the mine concession area (section 7.3)	x	x	x	x	x	x	x	x
- use all relevant baseline data to determine suitable species and methods for the restoration of identified offset sites (section 7.3)	x	x	x	x	x	x	x	x
- include appropriate stakeholders in participatory monitoring of the biodiversity offset sites to strengthen boundaries of responsibility and create credibility in the effectiveness of offsets actions and long-term outcomes (section 7.3)	x	x	x	x	x	x	x	x
- use the same monitoring procedures as in restoration sites to track biodiversity recovery in offset sites; (section 7.3, 8.1 – 8.3)								
- support the national park authority in protecting biodiversity-offset sites for an appropriate period of time following restoration, particularly fire prevention and cattle exclusion. (section 7.3)	x	x	x	x	x	x	x	x

Activity	Year							
	1	2	3	4	5	6-10	11-15	16-20
EDUCATION AND OUTREACH								
- Maintain the activities in the Siam Cement Lampang Mine Rehabilitation Study Center for seedling production (section 9.1)	x	x	x	x	x	x	x	x
- Provide educational activities and continue the cooperation with the local schools. (section 9.1)	x	x	x	x	x	x	x	x
- Cooperate with the educational institutions to develop in-depth research and improve rehabilitation practice (section 9.1)	x	x	x	x	x	x	x	x

The progress of all management actions should be monitored annually (or according to the time plan for each activity). The management action should then be adapted in response to the monitoring results to get a more effective measure for mine management. There are some adaptive management suggestions in the Gantt chart such as;

- The similarity of tree community in restored area and reference forest: if the similarity is lower than the accepted value, new species from the natural forest should be included in the seedling production and planting plan to increase the similarity between both areas
- Conservation of the species of concern: if the number of target animals is decline additional inputs actions to support the species should be applied (e.g. provided supplement food sources or captive breeding program)
- Invasive exotic species (*Leucaena leucocephala*) control: if the conventional eradication measure is not working, experiments to find a more effective method should be done.

APPENDIX

Appendix 1 Tree species in SCG (Lampang)

SPECIES	FAMILY	LOCAL NAME	Range	Commonness	SEEDLINGS IN GROUND FLORA?	BASELINE BIO-DIVERSITY STUDY
Acacia megaladena Desv. var. megaladena	Leguminosae, Mimosoideae	ขี้แรด	Medium	Rare	Yes	
Aegle marmelos (L.) Corr.	Rutaceae	มะตูม	Localized	Medium	Yes	
Afzelia xylocarpa (Kurz) Craib	Leguminosae, Caesalpinioideae	มะค่าโมง	Localized	Rare		Yes
Aglaia grandis Kurz	Meliaceae	ลางสาดป่า	Localized	Rare		Yes
Albizia lebbeck (L.) Benth.	Leguminosae, Mimosoideae	พฤกษ์	Localized	Rare	Yes	Yes
Albizia odoratissima (L. f.) Bth.	Leguminosae, Mimosoideae	กางขี้มอด	Localized	Rare		Yes
Anogeissus acuminata (Roxb. *ex* DC.) Guill. & Perr.	Combretaceae	ตะเคียนหนู	Patchy	Medium	Yes	
Anomianthus dulcis (Dunal) J. Sinclair	Annonaceae	นมวัว	Localized	Rare		Yes
Anthocephalus chinensis (Lmk.) A. Rich. *ex* Walp.	Rubiaceae	กระทุ่ม	Localized	Rare		
Antidesma acidum Retz.	Euphorbiaceae	เม่าสร้อย	Localized	Rare	Yes	
Antidesma sootepense Craib	Euphorbiaceae	มะเม่าสาย	Medium	Common	Yes	Yes
Aporusa villosa (Lindl.) Baill.	Euphorbiaceae	เหมือดโหลด	Localized	Rare		Yes
Artocarpus lacucha Roxb. *ex* Buch.-Ham.	Moraceae	หาด	Localized	Rare		Yes
Artocarpus lanceifolius Roxb.	Moraceae	หาดหนุน	Patchy	Rare		
Azadirachta indica A. Juss.	Meliaceae	สะเดา	Localized	Rare		
Baccaurea ramiflora Lout.	Euphorbiaceae	มะไฟ	Localized	Rare		Yes
Bauhinia bracteata (Grah. *ex* Bth.) Bak. ssp. *bracteata*	Leguminosae, Caesalpinioideae	เสี้ยวเครือ	Localized	Rare		
Bauhinia variegata L.	Leguminosae, Caesalpinioideae	เสี้ยวขาว	Medium	Rare		Yes
Berrya cordifolia (Willd.) Burret	Tiliaceae	เลียงมัน	Localized	Rare		Yes
Bombax ceiba L.	Bombacaceae	งิ้ว	Localized	Rare		Yes

SPECIES	FAMILY	LOCAL NAME	Range	Commonness	SEEDLINGS IN GROUND FLORA?	BASELINE BIO-DIVERSITY STUDY
Bridelia retusa (L.) A.Juss.	Euphorbiaceae	เต็งหนาม	Localized	Rare		Yes
Buchanania lanzan Spreng.	Anacardiaceae	มะม่วงหัวแม	Localized	Rare		Yes
Caesalpinia godefroyana Kuntze	Leguminosae, Caesalpinioideae	เถาหนามหัน	Localized	Rare		
Cananga latifolia (Hook.f. & Thomson) Finet & Gagnep	Annonaceae	สะแกแสง	Localized	Rare		Yes
Canarium subulatum Guill.	Burseraceae	มะกอกเกลื้อ	Medium	Rare		
Careya arborea Roxb.	Lecythidaceae	กระโดน	Localized	Rare		Yes
Casearia grewiifolia Vent.	Flacourtiaceae	สีเสื้อ	Medium	Medium	Yes	
Cassia fistula L.	Leguminosae, Caesalpinioideae	ชัยพฤกษ์	Localized	Rare		Yes
Catunaregam spathulifolia Tirveng.	Rubiaceae	เคด	Localized	Rare		Yes
Chukrasia tabularis A. Juss.	Meliaceae	ยมหิน	Patchy	Rare		Yes
Chukrasia velutina Wight & Arn	Meliaceae	ยมหิน	Localized	Rare		
Clausena excavata Burm.f.	Rutaceae	สมัดใหญ่	Localized	Rare		
Colona floribunda (Kurz) Craib	Tiliaceae	ปอมืน	Localized	Rare	Yes	
Colona winitii Craib	Tiliaceae	ปอตีนเต่า	Localized	Rare		
Combretum latifolium Bl.	Combretaceae	แหนเครือ	Localized	Rare		
Crateva sp. (M)	Capparaceae	หนวดกุ้ง	Localized	Rare		
Cratoxylum cochinchinense (Lour.) Blume	Guttiferae, Hypericace	ติ้วเกลี้ยง	Localized	Rare		Yes
Cratoxylum formosum (Jack) Dyer	Guttiferae, Hypericaceae	ติ้วขน	Localized	Rare		Yes
Croton roxburghii N.P.Balakr.	Euphorbiaceae	เปล้าใหญ่	Localized	Rare	Yes	Yes
Cryptocarya pallens Kosterm.	Lauraceae	หมากขี้อ้าย	Localized	Medium		
Dalbergia cana Grah. *ex* Kurz var. *cana*	Leguminosae, Papilionoideae	กระพี้นางนว	Localized	Rare	Yes	
Dalbergia cochinchinensis Pierre	Leguminosae, Papilionoideae	พะยูง	Localized	Rare		Yes
Dalbergia cultrata Grah. *ex* Bth.	Leguminosae, Papilionoideae	เก็ดดำ	Medium	Rare	Yes	Yes
Dalbergia foliacea Wall. *ex* Benth.	Leguminosae, Papilionoideae	เถาพี้	Localized	Rare		
Dalbergia oliveri Gamble	Leguminosae, Papilionoideae	ชิงชัน	Localized	Rare		Yes

SPECIES	FAMILY	LOCAL NAME	Range	Commonness	SEEDLINGS IN GROUND FLORA?	BASELINE BIO-DIVERSITY STUDY
Desmos sp.	Annonaceae	เนา	Localized	Rare		
Dialium cochinchinense Pierre	Leguminosae, Papilionoideae	หยี	Localized	Rare		Yes
Dillenia obovata (Blume) Hoogland	Dilleniaceae	ส้านใหญ่	Localized	Rare		Yes
Dillenia pentagyna Roxb.	Dilleniaceae	ส้านช้าง	Localized	Rare		Yes
Dioecrescis erythroclada (Kurz) Tirveng.	Rubiaceae	มะดังแดง	Localized	Rare		Yes
Diospyros mollis Griff.	Ebenaceae	มะเกลือ	Localized	Rare	Yes	Yes
Diospyros montana Roxb.	Ebenaceae	ถ่านไฟผี	Medium	Rare		Yes
Drypetes roxburghii (Wall.) Hurusawa	Euphorbiaceae	มะคำไก่	Localized	Rare	Yes	
Engelhardia spicata Lechen. *ex* Bl. var. *spicata*	Juglandaceae	ค่าหด	Localized	Rare		
Erythrina stricta Roxb. var. *stricta*	Leguminosae, Papilionoideae	ทองเดือนห้า	Localized	Rare		Yes
Erythrina subumbrans (Hassk.) Merr.	Leguminosae, Papilionoideae	ทองหลางป่า	Localized	Rare		
Eugenia albiflora Duth. *ex* Kurz	Myrtaceae	มะห้า	Localized	Rare	Yes	
Fernandoa adenophylla (Wall.ex G.Don) Steenis	Bignoniaceae	แคบิด	Localized	Rare		Yes
Ficus hispida L.f.	Moraceae	มะเดื่อปล้อง	Localized	Rare		Yes
Gardenia sootepensis Hutch.	Rubiaceae	คำมอกหลวง	Localized	Rare		
Garuga pinnata Roxb.	Burseraceae	ตะค้ำ	Localized	Rare		Yes
Gmelina arborea Rox	Verbenaceae	ซ้อ	Localized	Rare		Yes
Grewia eriocarpa Juss.	Tiliaceae	ต่องปล่า	Localized	Rare		Yes
Haldina cordifolia (Roxb.) Rids.	Rubiaceae	ขว้าว	Localized	Rare		Yes
Harrisonia perforata (Blanco) Merr.	Simaroubaceae	หนามจี้	Localized	Rare		
Holarrhena pubescens (Buch.-Ham.) Wall. *ex* G. Don	Apocynaceae	โมกหลวง	Patchy	Rare		Yes
Holoptelea integrifolia (Roxb.) Planch.	Ulmaceae	กระเชา	Localized	Rare		
Hymenodictyon orixense (Roxb.) Mabb.	Rubiaceae	สัมกบ	Localized	Rare		Yes
Kydia calycina Roxb.	Malvaceae	เลียงฝ้าย	Patchy	Medium		
Lagerstroemia calyculata Kurz	Lythraceae	ตะแบก	Localized	Rare		Yes

SPECIES	FAMILY	LOCAL NAME	Range	Commonness	SEEDLINGS IN GROUND FLORA?	BASELINE BIO-DIVERSITY STUDY
Lagerstroemia cochinchinensis Pierre var. *ovalifolia* Furt. & Mont.	Lythraceae	ปุ๊ยจิ้น,เปื้อย	Patchy	Rare	Yes	Yes
Lagerstroemia macrocarpa Wall.	Lythraceae	อินทานิลบก	Localized	Rare		Yes
Lagerstroemia tomentosa C.Presl	Lythraceae	เสลา	Localized	Rare		Yes
Lannea coromandelica (Houtt.) Merr.	Anacardiaceae	ก๊ก	Localized	Rare		Yes
Lepisanthes tetraphylla (Vahl) Radlk.	Sapindaceae	มะเฟืองช้าง	Medium	Rare	Yes	
Litsea glutinosa (Lour.) C.B. Rob.	Lauraceae	หมีเหม็น	Medium	Rare	Yes	
Lophopetalum duperreanum Pierre	Celastraceae	สองสลึง	Localized	Rare		Yes
Mallotus philippensis (Lmk.) M.A.	Euphorbiaceae	คำแสด	Localized	Rare	Yes	
Markhamia stipulata Seem. var. *stipulata*	Bignoniaceae	แคแดง	Localized	Rare	Yes	Yes
Melientha suavis Pierre ssp. *Suavis*	Opiliaceae	ผักหวาน	Localized	Rare		
Miliusa velutina (Dun.) Hk. f. & Thoms.	Annonaceae	ขางหัวหมู	Patchy	Medium	Yes	
Millettia brandisiana Kurz	Leguminosae, Papilionoideae	พี้จั่น	Widespread	Abundant		Yes
Millettia leucantha Kurz.	Leguminosae, Papilionoideae	สาธร	Localized	Rare		Yes
Millettia xylocarpa Miq.	Leguminosae, Papilionoideae	จักจั่น	Localized	Rare	Yes	
Millingtonia hortensis L. f.	Bignoniaceae	ปีบ	Localized	Rare	Yes	
Mitragyna rotundifolia (Roxb.) O.K.	Rubiaceae	กระทุ่มเงิน	Localized	Rare		Yes
Morinda coreia Ham.	Rubiaceae	ยอป่า	Localized	Rare		Yes
Morinda elliptica (Hk. f.) Ridl.	Rubiaceae	ยอป่า	Localized	Rare		Yes
Oroxylum indicum (L.) Kurz	Bignoniaceae	มะริดไม้	Medium	Medium		Yes
Phyllanthus columnaris M.-A.	Euphorbiaceae	ข้าวสาร	Medium	Rare		
Phyllanthus emblica L.	Euphorbiaceae	มะขามป้อม	Localized	Rare		Yes
Phyllanthus mirabilis Mull. Arg	Euphorbiaceae	ขี้เหล็กฤาษี	Localized	Rare		Yes
Phyllocarpus septentrionalis Donn. Smith	Leguminosae, Caesalpinioideae	ประดู่(แดง)	Localized	Rare		
Polyalthia cerasoides (Roxb.) Bth. *ex* Bedd.	Annonaceae	นมวัว	Localized	Rare		
Polyalthia obtusa Craib	Annonaceae	สามท้าว	Patchy	Rare		

SPECIES	FAMILY	LOCAL NAME	Range	Commonness	SEEDLINGS IN GROUND FLORA?	BASELINE BIO-DIVERSITY STUDY
Polyalthia simiarum (Ham. *ex* Hk. f. & Th.) Bth. & Hk. f.	Annonaceae	ยางโอน	Medium	Rare	Yes	
Polyalthia viridis Craib	Annonaceae	ยางโอน	Localized	Rare		0
Protium serratum (Wall. *ex* Colebr.) Engl.	Burseraceae	มะแฟน	Medium	Common	Yes	
Pterocarpus indicus Willd.	Leguminosae, Papilionoideae	ประดู่บ้าน	Localized	Rare		
Pterocarpus macrocarpus Kurz	Leguminosae, Papilionoideae	ประดู่	Widespread	Common	Yes	Yes
Pterolobium macropterum Kurz	Leguminosae, Caesalpinioideae	หนามจับ	Localized	Rare		
Rothmannia sootepensis (Craib) Brem.	Rubiaceae	ตาไหล	Localized	Rare		
Schleichera oleosa (Lour.) Oken	Sapindaceae	ตะคร้อ	Widespread	Medium		Yes
Schoepfia fragrans Wall.	Olacaceae	ขี้หนอน	Patchy	Rare		
Shorea siamensis Miq. var. *siamensis*	Dipterocarpaceae	ไม้รัง	Patchy	Rare		Yes
Siphonodon celastrineus Griff.	Celastraceae	มะดูก	Localized	Rare	Yes	
Spondias pinnata (L.f.) Kurz	Anacardiaceae	มะกอก	Localized	Rare		Yes
Sterculia villosa Roxb.	Sterculiaceae	ปอตุ้บหูช้าง	Localized	Rare		Yes
Stereospermum colais (Buch.-Ham. *ex* Dillwyn) Mabb.	Bignoniaceae	แคหิน	Localized	Rare	Yes	
Stereospermum neuranthum Kurz	Bignoniaceae	ปอตุ้มค้าย	Patchy	Rare		Yes
Streblus asper Lour. var. *asper*	Moraceae	ห่อยกำไม้ฝอ	Patchy	Rare		Yes
Strychnos nux-vomic a L.	Loganiaceae	แสลงใจ	Localized	Rare	Yes	Yes
Suregada multiflorum (A.Juss.) Baill.	Euphorbiaceae	ขันทองพยาบ	Localized	Rare		Yes
Syzigium cumini (L.) Skeels	Myrtaceae	หว้าขี้แพะ	Localized	Rare		Yes
Tamilnaldia uliginosa (Retz.) Tirveng. & Sastre	Rubiaceae	ตะลุมพุก	Widespread	Common		Yes
Terminalia alata Hey. *ex* Roth	Combretaceae	รกฟ้า	Patchy	Rare		Yes
Terminalia bellirica (Gaertn.) Roxb.	Combretaceae	สมอพิเภก	Widespread	Medium	Yes	Yes
Terminalia chebula Retz. var. *chebula*	Combretaceae	สมอไทย	Medium	Rare		Yes
Trema orientalis (L.) Blume	Ulmaceae	พังแหรใหญ่	Localized	Rare		Yes
Vitex canescens Kurz	Verbenaceae	ตีนนก	Medium	Medium	Yes	Yes

SPECIES	FAMILY	LOCAL NAME	Range	Commoness	SEEDLINGS IN GROUND FLORA?	BASELINE BIO-DIVERSITY STUDY
Vitex limoniifolia Wall. *ex* Kurz	Verbenaceae	ตีนนก	Localized	Rare	Yes	
Vitex peduncularis Wall.ex Schaur	Verbenaceae	กาสามปีก	Localized	Rare		Yes
Walsura robusta Roxb	Meliaceae	ขี้อ้าย	Localized	Rare		Yes
Wrightia arborea (Dennst.) Mabb.	Apocynaceae	โมกมัน	Medium	Rare		Yes
Xantolis cambodiana (Pierre *ex* Dub.) P. Royen	Sapotaceae	นมนาง	Localized	Rare		
Xylia xylocarpa (Roxb.) Taub. var. *kerrii* (Craib & Hutch.) Niels.	Leguminosae, Mimosoideae	แคง, ไม้แคง	Widespread	Common	Yes	Yes
Zollingeria dongnaiensis Pierre	Sapindaceae	ขี้หนอน	Patchy	Rare		
TOTAL NO. SPECIES			**127**	**127**	**32**	**76**

Appendix II Ground flora species
(B: Bush, F: Bryophyte, G: Grass, H: Herb, S:Shrub, V: Vine)

Species	Family	Habi	Abundance
Anomianthus dulcis (Dunal) J. Sinclair	Annonaceae	V	Medium
Baliospermum solanifolium (Burm.) Suresh	Euphorbiaceae	S	Uncommon
Barleria cristata L.	Acanthaceae	S	Medium
Bauhinia ornata var. *burmanica* K. & S.S. Larsen	Leguminosae, Caesalpinioideae	V	Common
Cayratia japonica (Thunb.) Gagnep.	Vitaceae	V	Rare
Cissampelos pareira L.	Menispermaceae	V	Medium
Clerodendrum serratum (Linn.) Moon	Verbenaceae	S	Rare
Congea tomentosa Roxb	Lamiaceae	V	Medium
Dendrocalamus membranaceus Munro	Gramineae	B	Uncommon
Desmodium gangeticum (L.) DC.	Leguminosae, Papilionoideae	V	Rare
Eupatorium odoratum L.	Euphorbiaceae	H	Uncommon
Gomphostemma strobilinum Wall. *ex* Benth.	Lamiaceae	H	Uncommon
Helicteres elongata Wall. *ex* Bojer	Sterculiaceae	S	Rare
Hymenopyramis brachiata Wall. *ex* Schauer	Verbenaceae	S	Medium
Leea indica (Burm. f.) Merr.	Vitaceae	S	Common
Myriopteron extensum Schum.	Periplocaceae	V	Abundant
Oplismenus compositus (L.) P. Beauv.	Gramineae	H	Uncommon
Oryza meyeriana (Zoll. & Moritzi) Baill. var. *granulata* (Watt.) Duist.	Gramineae	G	Rare
Piper sylvaticum Roxb	Piperaceae	V	Uncommon
Sauropus quadrangularis (Willd.) Müll.Arg.	Phyllanthaceae	S	Rare
Selaginella ostenfeldii Hieron	Selaginellaceae	F	Uncommon
Sphenodesme pentandra Jack.	Verbenaceae	V	Uncommon
Toxocarpus villosus (Blume) Decne.	Asclepiadaceae	V	Uncommon
Ventilago denticulata Gaertn.	Rhamnaceae	V	Uncommon
Zingiber bradleyanum Craib	Zingiberaceae	H	Rare
Ziziphus oenoplia (L.) Mill.	Rhamnaceae	S	Uncommon
Zygostelma benthamii Baill.	Asclepiadaceae	V	Medium